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Evaluation of Chemical Methods for Available Soil Phosphorus in Relation to Yield of Rice.

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EVALUATION OF CHEMICAL METHODS FOR AVAILABLE SOIL PHOSPHORUS IN RELATION TO YIELD OF RICE

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ABSTRACT

Twenty eight soil samples, each represented by a surface horizon, from the major rice growing areas of Louisiana were used in this investigation. Each sample represented the original soil condition where a replicated fertilizer response experiment was conducted with rice in the years 1963 through 1974. Percent yield was used to represent the dependant variable.

When the P in the naturally oxidized, naturally reduced, and artificially reduced conditions were compared, the ranking of the R^2 values using the quadratic equation to predict yield was: naturally oxidized > 0.1N $Na_2S_2O_4$ artificially reduced > naturally reduced > 0.2N $Na_2S_2O_4$ artificially reduced conditions.

When the air-dried soils were extracted by the chemical extractants, the ranking of R^2 in a decending order using the quadratic equation to predict yield was: Bray No.1 > Kapp's Texas Buffer > Bray No.2 > 0.5M $NaHCO_3$ > 0.2N HCl.

Reducing the soils naturally and then extracting them changed the ranking of the R^2 values to: 0.5M $NaHCO_3$ > Bray No.1 > Bray No.2 > 0.2N HCl > Kapp's Texas Buffer.

In the artificially reduced condition only the Bray No.1 showed a significant R^2 value both in the quadratic and

the cubic equations.

Artificial reduction is accomplished in one hour as compared to the naturally reduced which required from two to four weeks.

The study demonstrated that Bray No.1 showed a promising ability to correlate extractable phosphorus with rice yield (R^2 as high as 0.6401**), while 0.5M $NaHCO_3$ (R^2 as high as 0.5975**) also ranked high.

The natural and artificial reduction increased the amount of phosphorus extracted. This could be due to the conversion of ferric phosphate to ferrous phosphate which in turn was subjected to chemical extraction.

In the labile phosphorus experiment there were no significant R^2 values in the oxidized, naturally and artificially reduced soils irrespective of using linear, quadratic or cubic equations.

There were highly significant correlations of the labile P in 0.1N $Na_2S_2O_4$, 0.2N $Na_2S_2O_4$, naturally oxidized, and naturally reduced conditions. This gave a good indication that further investigation in this line of work would be beneficial.

The critical level of P for the nineteen P tests were determined by a graphical method and a one way analysis of variance. The critical level separated the soils into two definite groups:- (i) those on the left having a high probability of response to fertilizer P, and (ii) those to

the right having a low probability of response to fertilizer P.

Apart from finding the linear, quadratic, and cubic regression equations of percent yield to soil test P, the validity of Bray-Mitscherlich and Langmuir equations were evaluated. These two equations were used to transform the scattered points into the best fitting curve and thus the equations could also be used for predicting percent yield according to soil test results.

The Bray-Mitscherlich and Langmuir equations did fit in some of the analysis in this study. Instead of R^2 values the Sum of Squares of Deviation was used. When the air-dried soils were extracted chemically, 0.2N HCl, Bray No.1, and Bray No.2 had a lower percent deviation from the Langmuir equation.

It could be reported here that R^2 is not the only criteria to evaluate the superiority of an equation. Other factors like the shape of the curve should also be taken into consideration. In this respect the quadratic and cubic equations were not desirable. The Bray-Mitscherlich and Langmuir equations produced more desirable curves with the latter slightly superior.

INTRODUCTION

Phosphorus deficiency in plants is one of the major problems in soil fertility throughout the world. To make it worse, phosphate minerals comprise only a small fraction of the total inorganic matrix of soils. Greater emphasis is being made to understand which phosphate minerals can form in soils and how they influence the solubility of phosphorus.

The chemistry of phosphorus seems to be very complex both in the aerated and reduced soils. It has been demonstrated that when the soils are reduced as shown in rice cultivation, the phosphorus availability increased. One of the factors responsible is the reduction of ferric phosphate to ferrous phosphate. When that happens the phosphate is being made more soluble and available to rice plants. Unfortunately, it takes from two to four weeks for natural reduction to occur. If further investigations were to be made this gives a disadvantage in the lag of time spent. A procedure is needed that could reduce the soils to within an hour or two, so that the characteristics of reduced soils could be further investigated in greater details in a much shorter time.

The objectives of this investigation are as follows:

1. To evaluate the effectiveness of sodium dithionite in reducing the soils artificially to simulate the natural reduction that takes place in rice soils.
2. After the soils have been artificially reduced, the soils will be extracted by several chemical extractants. The phosphorus extracted will be correlated to the percent yield of rice.
3. To make use of radioactive phosphorus to determine the labile phosphorus of the soils.
4. To evaluate the fitness of (a) Modified Bray-Mitscherlich equation, and (b) Langmuir equation in correlating the above data to the percent yield of rice that has been grown on those soils.

REVIEW OF LITERATURE

Characteristics of Flooded Soils

Flooding has a marked effect on the physical, chemical, and biological characteristics of the soils.

(i) Gaseous Exchange

The immediate consequence of flooding is an interruption of the normal process of gaseous exchange between the air and the soil. Gas exchange between the atmosphere and the soil is essentially confined to the surface layer of the soil, below which oxygen is nonexistent (Patrick and Sturgis, 1955; Patrick, 1960; Ponnamperuma, 1965). As soon as soil is flooded the oxygen level begins to decline. Within 6 to 10 hours after a dry soil is flooded, the oxygen level drops to near zero. A reduced soil consumed oxygen more rapidly than an aerobic soil when submerged in oxygenated water (Patrick and Sturgis, 1955; Patrick, 1960; Ponnamperuma, 1965). In addition they also reported that O_2 does not penetrate into more than one cm of a flooded soil.

The rapid disappearance of oxygen from the soil is accompanied by an increase of carbon dioxide, nitrogen, methane, and hydrogen, produced largely through processes of microbial respiration. These gases vary in composition from

about 1 to 20% CO_2, 10 to 95% N_2, 15 to 75% CH_4, and 0 to 10% H_2 (Patrick and Mikkelsen, 1971).

The rate of diffusion of O_2 through the water-filled pores of a submerged soil is about one-tenthousandth of the rate of diffusion through the air-filled pores of a well-drained soil. In rice fields and shallow lakes the O_2 concentration of the water overlying the soil remains relatively high due to a rather low density of O_2-consuming organisms, due to photosynthetic O_2 production by algae, and due to mixing of the water by wind action and convenction currents. The thickness of this oxidized surface zone depends upon the balance between the rate of O_2 diffusion into the soil and the rate of consumption by the soil.

(ii) Changes in Redox Potential

The physicochemical measurement that best differentiates a flooded soil from a well-drained soil is the oxidation-reduction, or redox potential (Eh). Basically, the potential of the system (Eh) is proportional to the logarithm of the ratio of oxidant to reductant as well as the temperature of the particular system under consideration. The redox potential of waterlogged soils have been used to characterize the intensity of reduction. According to Smith et al. (1976), redox measurements in soil are not quantitative, but they are a good indication of reducing and oxidizing conditions in the soil profile.

Oxidized soils are characterized by redox potentials

of +400 mv or greater, whereas waterlogged soils have redox potentials as negative as -300 mv if the reduction processes are sufficiently intense.

Factors important in controlling Eh are temperature, flooding time, soil water content, and energy source. A 5°C increase in temperature at the 15-cm depth resulted in a 50-mv decrease in redox potential (Meek and Grass, 1975).

(iii) Reduction of Soil

In many rice soils, the thickness of the reduced layer underlying the oxidized zone varies from 15 to 20 cm (Mitsui, 1954). It is further characterized by bluish-gray color, no oxygen, a low oxidation-reduction potential and the presence of reduced products such as ammonia, nitrous oxide, ferrous, manganous, and sulfide ions and the products of anaerobic decomposition of organic matter such as aldehydes, alcohols, organic acids, mercaptans, amines, etc.

Nitrate, nitrite, and manganese dioxide are reduced at fairly high redox potential, whereas sulfate is reduced only under strict anaerobic conditions associated with redox potentials of about -150 mv and lower and the availability of an energy source to the microorganisms. Hydrated ferric oxide is intermediate between the two (Patrick and Mikkelsen, 1971). The amounts of various reduction products depend upon the quantities originally present in the soil and the extent to which the reduction process proceeds. The reduction of soil components is somewhat sequential, with

nitrate, nitrite, and manganic compounds being reduced first, followed by the reduction of ferric compounds and then the reduction of sulfate. Studies have shown that oxygen and nitrate are depleted from the soil before ferric iron is reduced and no sulfate is reduced to sulfide in the presence of oxygen and nitrite (Patrick and Mikkelsen, 1971).

The amounts of energy available to microorganisms has a major effect on how low the Eh decreased in a flooded soil (Meek and Grass, 1975).

Soil reduction does not appear to limit rice growth, except possibly at the extremely low redox potentials in low-iron soils where free hydrogen sulfide may be formed, or in soils that have a low pH and high concentration of ferrous iron. Maintaining the redox potential of a flooded rice soil at an intermediate value is of some benefit because at this point, all of the oxidation-reduction systems that function between the oxygen-water and sulfate-sulfide systems will serve to buffer the potential at intermediate values. Hydrated ferric oxide which is present in high amount in rice soils is important in preventing the redox potential from reaching extremely low values (Patrick and Mikkelsen, 1971).

(iv) pH

The pH of most soils tends to change toward the neutral point after flooding, with acid soils increasing and

alkaline soils decreasing in pH (Redman and Patrick, 1965; Ponnamperuma, 1965). Ponnamperuma (1955) suggested that a change in equilibrium between ferrous and ferric iron was responsible for decrease in H^+ concentration. The equilibrium pH for waterlogged soils is usually between 6.5 and 7.5. The tendency for soils of low pH to decrease in acidity and for soils of high pH to increase in acidity upon flooding indicates that the pH of a submerged soil is buffered around neutrality by substances produced as a result of reduction reactions.

Patrick (1964) explains an increase in pH accompanying a decrease in Eh on the basis that at low Eh ferric hydroxide is reduced to ferrous hydroxide as follows:

$$Fe(OH)_3 + e^- \rightleftharpoons Fe(OH)_2 + OH^-$$

and the simultaneous production of OH ions increase the pH. Manganese compounds in the form of hydroxides and carbonates, and carbonic acids may also be involved in buffering the pH of waterlogged soils.

(v) Ionic Strength

Ionic strength of a soil rises rapidly in the early stage of flooding which is attributed to the increase in ammonia, iron, manganese and other bases (Ponnamperuma, 1965). In slightly acid and acid soils, the reduction of insoluble iron, and possibly manganese compounds, to more soluble forms accounts for much of the increase in cations. In

neutral to slightly alkaline soils, calcium and magnesium in the soil solution make significant contributions to the ionic strength (Patrick and Mikkelsen, 1971).

(vi) Chemical and Biological Changes

Within a few hours after waterlogging, the aerobic organisms present exhaust the soil-contained oxygen supply. Some of the significant chemical and biological changes resulting from flooding the soil are: (1) Reduction of NO_3^-, Mn^{++++}, Fe^{+++}, and SO_4^{--}, (2) accumulation of ammonia and products of anaerobic metabolism of microorganisms, and (3) increase in solubility of phosphorus and silicon. The increase in magnitude of these changes are dependent on absence of NO_3 and MnO_2, the presence of high organic matter and depth of flooding (Ponnamperuma, 1965).

Submerging the soils bring about an increase in extractable phosphorus mainly by reduction of ferric to ferrous phosphate and hydrolysis of ferric and aluminium phosphates. Surface flooding of a sandy soil with raw domestic sewage water induced an accumulation of phosphates in the top 50-cm layers (Beek et al., 1977). They also found that accumulated phosphates mainly consisted of inorganic phosphate forms (80 to 85%). These inorganic phosphates were mainly bound to aluminium.

Effect of Flooding on Transformation of Soil Phosphorus

The behavior of phosphate in submerged soils is different from its behavior in upland soils. This phenomena is of utmost practical importance in the study of rice fertilization.

(i) Effect of Continuous Flooding

Mitsui (1954), Shapiro(1958a, 1958b), Stelly and Ricaud (1960) demonstrated that lowland rice frequently does not respond to phosphate fertilization, even though an upland crop grown on the same soil may give a positive response to P application.

The plant availability and the distribution patterns of the different phosphate fractions may be altered by reducing conditions brought about by seasonal flooding. The reductant-soluble iron phosphate is obviously of importance in the phosphate fertility of submerged soils.

Khalid, et al., (1977) showed that more soil P was released under reduced than oxidized conditions, and this increase in soluble P under reduced conditions was significantly related to strong Bray extractable P, clay content, and oxalate Fe. They further found a closer relationship between P sorbed and oxalate extractable Fe under reduced conditions. This indicates that poorly crystalline and amorphous oxides and hydroxides of Fe play a primary role in P retention by flooded soils and sediments. A probable

greater surface area generated by the transformation of oxyferric hydroxide to more reactive ferrous compounds may be responsible for greater P sorption under reduced conditions.

The mechanism of phosphate release in flooded soil may be explained by (1) reduction of insoluble ferric phosphate to more soluble ferrous phosphate (Islam and Elahi, 1954), (2) release of occuluded phosphate by reduction of hydrated ferric oxide coatings (Chang and Jackson, 1958), (3) displacement of phosphate from ferric and aluminum phosphates by organic anions (Bradley and Sieling, 1953), (4) hydrolysis of ferric and aluminum phosphates due to increase in alkalinity (Ponnamperuma, 1955), (5) anionic phosphate exchange between clay and organic anions (Russell, 1962), and (6) hydration of ferric and aluminum phosphates (Ponnamperuma, 1955).

Soils derived from marine (or brackish) sediments have high total P contents and high ratios of readily soluble P to total P (Kawaguchi and Kyuma, 1969).

Both pH and Eh had marked effects on the dissolution of strengite in flooded soil. At all pH level decreases in the Eh increased the amounts of iron and phosphate dissolved. The amounts dissolved were greater, however, at the lowest pH value. In highly reduced conditions, a decrease in pH resulted in a large increase in the amounts of iron and phosphate dissolved, whereas under more oxidizing condition, pH had much less effect on the amounts of iron and phosphate dissolved (Patrick et al., 1973b). The dissolution

of strengite ($FePO_4.2H_2O$) with the production of Fe^{++} and $H_2PO_4^-$ which occured as both pH and Eh were decreased suggests that strengite dissolution in flooded soils may be described by the following equation:

$$FePO_4.2H_2O + 2H^+ + e^- \rightleftharpoons Fe^{++} + H_2PO_4^- + 2H_2O$$

$$E_{ii} = E^o - 0.059 \log Fe^{++} - 0.059 \log H_2PO_4^- - 0.118pH$$

where E_{ii} represents the potential for the reversible reaction and E^o is the potential when all substances are at unit activity (Patrick et al., 1973b).

Mitsui (1964) indicated that rice plants develop lysigenous gas spaces (aerenchyma) linked with the air space of the root system as a reaction to oxygen stress. Oxygen moves into the roots and to the soil through these channels oxidizing the rhizosphere. New nodal roots with strong oxidative power develop successively with plant growth. The oxidative zone developed in the rhizosphere of the plants acts as a protective area against toxic amounts of harmful reducing substances such as ferrous Fe and sulfides (Takijima, 1965).

Iron and Mn are readily oxidized from their ferrous and manganous forms to insoluble forms by rice roots and deposit on the surface of the roots (Ponnamperuma, 1965; Takijima, 1965; Howeler, 1973; Bacha and Hossner, 1977).

Campbell and Racz (1975) found that mineralization of organic P in laboratory experiments was greater in

flooded soils than in soils maintained at field capacity. The anaerobic condition existing in soil beneath the feedlot was likely conducive to a rapid mineralization and depletion of organic P in the soil. In addition rates of mineralization were greater for manured than for non-manured samples.

Chien (1977), found that the concentration of P in the soil solution equilibrated with various phosphate rocks during incubation varied considerably among sources of the rock, ranging from 0.03 to 0.35 ppm in one week and 0.04 to 0.11 ppm in ten weeks after the soil was flooded. The solubility differences of various phosphate rocks decreased as incubation time increased.

Phosphate Forms and Their Distribution

The phosphates in soils may be divided into two broad categories, (i) organic and (ii) inorganic.

(i) Organic Phosphorus Compounds in Soils

There has been relatively less work done on the organic P compounds in soils. One of the reasons for lack of information on these compounds is because they apparently are exceedingly complex. There are three main groups of organic P compounds found in plants are also present in soils (Bower, 1949). These are (a) nucleic acids (b) phospholipids, and (c) phytin and phytin derivatives.

The phosphate supply from organic compounds is

dependent upon their rate of mineralization. Nucleic acids are major components of the organic P.

A number of investigators report a decrease in P sorption by soils in the presence of organic matter (Dalton et al., 1952; Vyas, 1964; Gaur, 1969). The common belief of these workers is that organic matter decomposition produces organic acids which form stable complexes with Fe and Al and consequently block P retention by them. On the contrary, other researchers report that organic matter increases the P retention by the soil (Rennie and McKercher, 1958; Larsen et al., 1959; Harter, 1969). Some have suggested that this results from microbial assimilation.

Caldwell and Black, (1958II) demonstrated that soil microorganisms are capable of synthesizing inositol hexaphosphate and suggest that all the supposed isomer and part of the meso-inositol hexaphosphate of soils presumably is not synthesized by higher plants. According to Caldwell and Black, (1958III) the content of organic P in forms other than inositol hexaphosphate provided the best prediction of inositol hexaphosphate phosphorus. They further verified that the percentage content of inositol hexaphosphate phosphorus in the organic P was higher in soils developed under forest vegetation (24%) than under grassland vegetation (14%) and decreased with increasing pH in both types of soils. Singh and Jones (1976) suggest that microbial decomposition of added organic residues changes sorption and desorption of P by the soil. Rolston et al., (1975) stated

that all the organic phosphates hydrolyzed at similar rates. The P from all the organic compounds moved to approximately the 12-cm depth in the calcareous Panoche clay loam soil with only slight differences in P concentration above that depth, whereas inorganic phosphate moved no more than 2-3 cm. The enzymatic hydrolysis rate of glycerophosphate and the resulting P distribution after infiltration was influenced by soil type. However, Campbell and Racz (1975) demonstrated that organic and inorganic P moved at about equal rates in soil treated with a manure extract.

Van Diest and Black (1959) report that P present in the organic form at the beginning of a season contributes substantially to plant nutrition in that season.

Inorganic Phosphorus Compounds in Soils

Inorganic phosphates in soils may be classified according to their physical, mineralogical, or chemical nature or the combination of these. They can be seperated into four main groups; calcium phosphate, aluminum phosphate, iron phosphate, reductant soluble iron phosphate (Chang and Jackson, 1957a). Iron, aluminum and calcium phosphates also include adsorbed and surface precipitated phosphates associated with the respective types of soil particles. The extensity of phosphate surface of various chemical forms determine to a certain degree the availability of soil P to plants. Therefore, fractionation of soil P is of value in

the fields of soil chemistry, soil fertility, and soil genesis (Chang and Jackson, 1957a). Calcium phosphate exists mainly as apatite but dicalcium, monocalcium, and octacalcium phosphates also exist in small amounts or as transitional forms. The four P fractions (NH_4Cl-soluble, Al, Fe, and Ca) comprised a major part (62 to 92%) of the total inorganic P in the soils (Halstead, 1967).

Phosphate residues in the soil were subdivided into three fractions on the basis of isotopic exchange of orthophosphate ions between the soil and the soil solution. It was observed that the total labile P was a smaller fraction of the total P in the heavier soils than in the lighter soils. This could be partly attributed to a higher organic-phosphorus content in the heavier soils (Talibudeen, 1958).

Kawaguchi and Kyuma (1969) found that goethite is the only crystalline iron oxide mineral found in Malayan paddy soils.

Phosphate Activity and Equilibria

The activity concept of phosphate-rock solubility was proposed by Chien and Black (1975, 1976) based on an equilibrium method. According to this concept, the apatite in rock is not uniform in solubility. Preliminary extraction with dilute acid solution dissolves the small, but more soluble, portion and leaves the less soluble portion behind. Chien (1977a), who tested the phosphate-rock kinetically

found that the rate constant depends on the degree of carbonate substitution for phosphate in apatite structure and the solid / solution ratio used.

The free energies of formation calculated from the carbonate apatites (ΔG^{o}_{f}, CA) in various phosphate rocks increased linearly with an increase in the number of moles of carbonate / mole of apatite (Chien and Black, 1976; Chien, 1977b). They further said that the empirical equations developed to relate the the ΔG^{o}_{f}, CA values to the number of moles of carbonate / mole of apatite make possible the estimation of K_{CA} (ion-activity product or solubility-product constant) for other phosphate rocks for which the empirical molecular formula of the apatite is known.

Ryden and Syers (1977) found that the values of the sorption energy constants suggested that sorbed P existed in two very distinct forms, namely chemisorbed P and more-physically sorbed P which involved a potential-determining (p.d.) sorption mechanism. An isotherm for each sorption type was developed which permitted the calculation of the amounts of P sorbed in each form by each soil.

Bennett and Adams (1976) found that the acceptable "calculated" $p(Ca^{++})(HPO_4^{--})$ limits for soil solutions to be considered saturated with $CaHPO_4.2H_2O$ should be 6.4 and 6.6. They concluded that the presence of excess $CaHPO_4.2H_2O$ in soil could be inferred by ion-activity products of displaced soil solutions.

Lime and neutral calcium salts often increase the

strength of phosphate sorption in soils and soil minerals (Rajan and Fox, 1972), and the effect has been attributed to increased calcium activity in experiments with gibbsite (Helyar et al., 1976). Accordingly, Munns and Fox (1976) found in the Wahiawa soil, lime lowered initial (P) and therefore the absolute rate of decline in (P), but it did not affect the relative rate of decline in (P). This is consistent with the simple interpretation that the slow reaction rate depends on (P) for a given adsorbent.

Kafkafi et al., (1967) reported that when a phosphate solution containing ^{32}P is added to kaolinite with adsorbed phosphate isotopic exchange takes place. They further suggested that the amount of adsorbed phosphate at any point on a washing (desorption) isotherm is made up of two types of surface phosphate, one category is fixed and does not make detectable contributions to the solution, whereas the other dominates the equilibrium with the solution phase and corresponds with the direct adsorption isotherm.

Measurements of pH of the equilibrium P solutions suggested that there was deprotonation of the $H_2PO_4^-$ ion during the initial stages of adsorption. Similar results were obtained when the Dowex 1-X8 were saturated with the IO_3^- ion and P adsorption on the resin studied (Taylor and Ellis, 1978). They further concluded that at low concentrations P was bounded by two points of attachment after deprotonation of the $H_2PO_4^-$ ion, followed by one point of attachment at higher P concentrations during adsorption on the

resin surface. This resulted in the deviation from linearity predicted by the Langmuir equation.

For forty-one soils (pH > 5.0) from southern England and eastern Australia, the Langmuir equation was an excellent model for describing P adsorption from solutions $< 10^{-3}$M P, if it was assumed that adsorption occurs on two types of surface of contrasting bonding energies (Holford et al., 1974).

Langmuir adsorption isotherms showed that Maumee River Basin sediments had adsorption capacities 10 to 20 times greater than Basin soils (McCallister and Logan, 1978; Green et al., 1978). The increase in total P over soils is attributed to enrichment of P in sediment by selective erosion of fine particles and adsorption of P during fluvial transport. The suspended sediment had higher adsorption maxima than Basin soils but lower than bottom sediments and had lower adsorption energies than either soils or bottom sediments (Green et al., 1978). Bray P_1 "available" P was highly correlated with EPC (equilibrium phosphorus concentration) and P desorbed in the soils but to a lesser extent in the bottom sediments. Citrate-dithionite-bicarbonate and oxalate extractable-P was highly correlated with P adsorption capacity in the bottom sediments but not in the soils (McCallister and Logan, 1978).

Solubility and Availability of Phosphate in Soils

The insolubility of iron and aluminum phosphates and the very low solubility of the calcium phosphates (except monocalcium phosphate), forces plants, in the majority of cultivated soils, to absorb their P from a very dilute solution of the element. Sodium, potassium, ammonium and magnesium phosphates which are quite soluble, occur in very few soils, and when present other characteristics render the soil a poor medium of plant growth.

Siegel et al., (1977) mentioned that the ashes of barley and wheat straws contained less P than did the ashes of pine and fir bark and almond trimmings. The amounts of P absorbed by the plants at a given soil solution level increased with clay content. This indicates that the clay content is a prime factor in P availability (Francisco Baldovinos and Thomas, 1967). It is suggested (Burleson and Page, 1967) that P and Zn react together within the roots in a manner that reduces either their mobility or solubility.

Depletion of soil solution P from zones around plant roots indicates that the diffusive flux of P from the soil solution to the plant root is inadequate to keep pace with removal by plant roots. Consequently, the concentration and / or concentration gradients of solution P maintained under conditions of repeated removal over time are an important soil property that is a factor in determining the quantity of P diffusing to root surfaces (Peaslee and Ballaux,

1977). An increase in pH of soils from the savannah zones of Nigeria to which varying quantities of phosphate were added increased the phosphate adsorbed by the soils. It is suggested that high pH increased the activity of hydroxy-aluminum. Phosphate was adsorbed on the surface of the hydroxy-aluminum species when the hydroxy-aluminum-phosphate attraction was strong enough to displace surface OH^- ions (Uzo Mokwunye, 1975).

Kunishi and Taylor (1975), measured the apparent bulk phosphate self-diffusion coefficient, resin extractable and isotopically exchangeable phosphate on a Cecil sandy loam soil pre-treated with calcium carbonate and monocalcium phosphate. They showed that at the higher phosphate addition, the amount extractable by the resin over 16 hours was about twice as great as that exchangeable with ^{32}P over the same period. At the lower rate of addition no significant differences were found.

The P concentrations in the soil equilibrated with phosphate rocks reached a maximum one to three weeks after the soil was flooded. There was a linear relationship ($r=0.93$) between the logarithm of the maximum P concentrations in the soil solution equilibrated with phosphate rocks and the degree of carbonate substitution for phosphate in the apatite structure of the phosphate rocks used (Chien, 1977c).

Phosphate Fertilization

The immediate source of P for plants growing in soils is probably that supplied by the inorganic P in the soil solution. Nevertheless, for maximum production of crops, P has to be supplemented by phosphate fertilizers.

Bennett and Adams (1976) found that the soil-solution data showed that broadcast applications of P fertilizer are not likely to result in $CaHPO_4.2H_2O$ being present as one of the reaction product of P.

Ammonium polyphosphate and diammonium phosphate were used as a source of P for corn (Zea mays L.). Both sources increased dry weights, uptake of P by the plants, and available soil P in a slightly acid soil but not that much in a alkaline-calcareous soil (Subbarao et al., 1975). Total P and $NaHCO_3$-P data for subsurface samples from the monoammonium phosphate-treated Oxbow soils indicated that virtually all of the applied P remained in the Ap horizon (Sadler and Stewart, 1975).

Safaya (1976) demonstrated that iron concentration in plants decreased with Zn application but significant reduction in Fe flux with Zn occured during early growth of 25 ppm P-supplied plants only. The addition of 20 mg of unlabeled rock phosphate per gram of soil resulted in greater diffusion of ^{32}P from 100 percent acidulated rock phosphate than when no rock phosphate was added (Logan and McLean, 1977). Singh and Jones (1976) showed that P fertilizer

rates estimated from sorption isotherms may need to be modified following addition of organic residues.

Munns and Fox (1976) said that the soils that they equilibrated behaved as if 30 to 60% of the added phosphate still remained labile. Therefore, phosphate in these soils should have substantial residual value, and this value should be permanent except for removals by cropping and erosion. This agrees with other evidence of large residual effects in similarly highly weathered tropical soils some years after field application of phosphate (Fox et al., 1968; Brams, 1973).

Field studies of P uptake by tomato seedlings show that when P was applied through the drip system, the P content in tomato seedling leaves was greater than if the same rate was applied in a band beneath the seed at planting (Rauschkolb et al., 1976). They further said that with drip irrigation, orthophosphate moved a much greater distance into the soil.

Correlation of Soil Tests with Crop Response

Methods for determining P in soils have been discussed in the literature for decades. No one universal method has been successfully established to measure soil P. Each method has its own specificity in use and limitations. In 1948, Bray designed a procedure in which the soil test was correlated with percentage yield of the crop grown.

Halstead (1967) who used the percent yield [(yield without P x 100) / (yield with P)] found that neither the Fe - nor Ca - P fraction was related to yield. There was a significant correlation between the Al-P and Fe-P fractions and available P as measured by the $NaHCO_3$ method. The Al - and Fe - P were strongly associated with the degree of P saturation, and Fe - P was associated with the P retention capacity of the soils.

Baker and Hall (1967) found that the weak Bray method was most accurate for predicting plant uptake of P. They further said that the weakness of most P extractants was the presence of free $CaCO_3$, or other compounds more soluble in the extractant than fixed P which caused the extractant to remove less P than it should.

A comparison of several methods used for the determination of total P in soils showed that Na_2CO_3 fusion is the most reliable method for samples which contain apatite inclusions and that the effectiveness of extraction was usually in the order: Na_2CO_3 fusion > HF digestion > $HClO_4$ digestion > $\underline{N}$ H_2SO_4 extraction following ignition (Syers et al., 1967).

Sree Ramulu et al., (1967), in a study on P fixation by 12 acid soils that contained various amounts of free iron oxides, found a significant correlation ($r = 0.77$) between P fixation and dithionite extractable Fe, but regression analysis showed that soils which contained kaolinite as the only clay mineral fixed more P. They further confirmed that Fe

in the interlayers of vermiculite is not active in P fixation but is extractable with dithionite but not by oxalate. The amounts of Fe extracted with oxalate were significantly correlated with P fixation ($r = 0.95$).

Kawaguchi and Kyuma (1969) combined the various methods already available in literature for estimating the availability of soil P. They used the following four P determination methods; (1) total P of air-dried soils, (2) 0.2N HCl soluble P of air-dried soils (routinely used in Japan), (3) Bray-Kurz No.2 soluble P of air-dried soils, and (4) 0.2 N HCl soluble (or Bray-Kurz No.2 soluble, for fewer samples) P after two weeks anaerobic incubation of air-dried soils.

The amounts of inorganic P extracted by the Olsen bicarbonate reagent, or those which were isotopically exchangeable during 30 minutes, were found to be considerably greater than the amounts of more-physically sorbed P resulting from several different P additions to each soil (Ryden and Syers, 1977).

Ballard and Pritchett (1975) found that the amounts of P extracted by H_2O or NH_4OAc (pH 4.8) were the most closely correlated with height growth and response to P fertilization for Pinus elliottii after one year of growth in both the greenhouse and field. They further found that methods which extracted larger amounts of P - 0.5M $NaHCO_3$; 0.5 N HCl + 0.025 N H_2SO_4; 0.03 N NH_4F + 0.025 N HCl - were more effective predictors of response to P fertilization

over growth periods of three and five years in the field. Phosphorus extracted by 0.03 N NH_4F + 0.025 N HCl was the most closely correlated with response recorded after five years (r^2 = 0.778).

The increase in sediment inorganic P, which occured when phytoplankton growth diminished, were due principally to increase in P mineral components soluble in NH_4F, indicating that resorbed P was F - exchangeable and / or associated with crystalline and amorphous Al-P components. Changes in the form of sediment P which occured in the lake and in laboratory equilibrium studies, indicated that conversion of resorbed NH_4F soluble-P to NaOH (0.1 M) and citrate-dithionite soluble-P, must be a relatively long term (> two years) process (Wildung et al., 1977).

In the determination of available soil P, Enwezor (1977) found that strong alkali extraction using 0.1 N NaOH extracted the most P but was the least precise in predicting yields (r = 0.58).

Bowman et al., (1978), evaluated four determinations of phosphorus - Olsen-P, Colwell-P, total exchangeable P, and resin-extractable P in terms of total plant P uptake in a 3-year continuous greenhouse study of 23 high P calcareous and neutral soils. They found that all methods were highly correlated with the total P taken up from the soils by five to eight successive greenhouse crops.

Tahir, (1978), found highly significant correlations between P extracted from the Norwood and Dexter soils by all

the chemical methods (weak Bray, strong Bray, double acid, modified Olsen, Mississippi method, and NH_4OAc) and P uptake and the dry matter production of two crops of corn grown in the greenhouse.

Determination of Phosphorus

The determination of P based on the formation of the molybdenum blue complex has been investigated by many researchers (Murphy and Riley, 1962; Watanabe and Olsen, 1965). These investigators concluded that the intensity of the blue color is highly dependent upon pH, ammonium molybdate concentration, and the concentration of the reducing agent.

When determining P by the method of Murphy and Riley, turbidity caused severe interference. The combination of Sb and NH_4 in solution during color development causes turbidity interference. The turbidity could be eliminated by raising the pH above 8.2 with NaOH and boiling to drive off NH_4^+ as NH_3 gas prior to color development or by substituting heat for Sb to develop the characteristic molybdenum blue color (Folsom, et al., 1977). A simple and rapid procedure for the determination of inorganic P in acid ammonium oxalate extracts of soil was developed by modifying the ascorbic acid-molybdenum blue calorimetric method (Owens et al., 1977). They managed to overcome the oxalate interference in the determinations of P by addition of excess ammonium molybdate. A molar ratio of molybdate to oxalate, in the final solution,

of 2.51:1 was required in order to eliminate the oxalate interference.

Helyar and Brown (1976) used octan-I-ol for the analysis of orthophosphate in aquous solution with a detection limit of less than 0.1 ug orthophosphate P and the molybdophosphoric acid can be concentrated at least 300 times by extraction into octan-I-ol. The technique was used successfully to analyze for phosphate in calcium chloride extracts from soil. Dick and Tabatabai (1977) developed a simple and precise colorimetric method of determining orthophosphate in aqueous solutions containing labile organic and inorganic P compounds. It involves a rapid formation of molybdenum blue color by the reaction of orthophosphate with molybdate ions in the presence of ascorbic acid-trichloroacetic acid and citrate-arsenite reagents and complexing of the excess molybdate ions to prevent further formation of blue color from the phosphate derived from hydrolysis of the acid-labile P compounds. The method is sensitive and accurate, and it permits determination of microgram quantities of orthophosphate in samples containing large amounts of acid-labile P compounds. Results of this method are comparable to that of Murphy and Riley.

MATERIALS AND METHODS

Experimental Materials

Twenty eight soil samples, each represented by a surface horizon, from the major rice areas of Louisiana were obtained through Dr. D. B. Mengel, of the Rice Experiment Station Crowley, Louisiana. Each sample represented the original soil condition where a replicated fertilizer response experiment was conducted with rice by Dr. D. B. Mengel and Dr. F. J. Peterson. A total of 28 sites and soils were involved in the years 1963 through 1974.

A brief description of the soils is given in Table 5.

Methods

The air-dried soils were extracted by several chemical methods (0.5M $NaHCO_3$, Kapp's Texas Buffer, Bray No.1, Bray No.2, and 0.2N HCl) to evaluate their effectiveness.

Sodium dithionite was used to establish an artificial reduction condition to simulate the natural reduction taking place in rice field. After the soils have been naturally and artificially reduced, they were extracted with the above mentioned procedures. Experiments were also carried out to determine labile phosphorus, inorganic phosphorus fractionation, and Eh and pH.

Table 1

Soil Area, Soil Series, Year and Location of the Rice Fertilizer Response Experiments(x)

Soil No.	Soil Area(y)	Soil Series & Textural Class(z)	Date Planted	Location
201	1	Midland sil	1963	Rice Experiment Station Crowley, Acadia Parish
202	2	Iberia c	1964	Vira Laughlin Farm, St. Martin Parish
203	1	Crowley sil	1964	Unkel Farm, Allen Parish
204	1	Bernard vfsl	1964	Sweet Lake Land and Oil Company, Calcasieu Parish
205	1	Harris sil	1964	Ellis Stansel Farm, Vermilion Parish
206	1	Crowley sil	1964	Rice Experiment Station Crowley, Acadia Parish
207	1	Midland sil	1964	Rice Experiment Station Crowley, Acadia Parish
208	3	Sharkey c	1964	E.E. Edmundson, Jr. Farm, East Carroll Parish
209	2	Alligator sicl	1965	Vira Laughlin Farm, St. Martin Parish
210	1	Midland fsl	1965	Sweet Lake Land and Oil Company, Cameron Parish

Table 1 (Continued)

Soil No.	Soil Area(y)	Soil Series & Textural Class(z)	Date Planted	Location
211	1	Harris sil	1965	Ellis Stansel Farm, Vermilion Parish
212	1	Crowley sil	1965	Rice Experiment Station Crowley, Acadia Parish
213	1	Midland sil	1965	Rice Experiment Station Crowley, Acadia Parish
214	3	Sharkey c	1965	E.E. Edmundson, Jr. Farm, East Carroll Parish
215	1	Midland fsl	1966	Sweet Lake Land and Oil Company, Cameron Parish
216	1	Crowley sil	1966	Unkel Farm, Allen Parish
217	1	Patoutville sil	1966	Alvin Richard Farm, Vermilion Parish
218	1	Crowley sil	1966	Rice Experiment Station Crowley, Acadia Parish
219	1	Midland sil	1966	Rice Experiment Station Crowley, Acadia Parish
220	1	Midland fsl	1967	Sweet Lake Land and Oil Company, Cameron Parish
221	1	Patoutville sil	1967	Alvin Richard Farm, Vermilion Parish

Table 1 (Continued)

Soil No.	Soil Area(y)	Soil Series & Textural Class(z)	Date Planted	Location
222	1	Crowley sil	1971	Rice Experiment Station Crowley, Acadia Parish
223	1	Crowley sil	1971	Rice Experiment Station Crowley, Acadia Parish
224	1	Crowley sil	1972	Rice Experiment Station Crowley, Acadia Parish
225	1	Crowley sil	1972	Rice Experiment Station Crowley, Acadia Parish
226	1	Crowley sil	1973	Rice Experiment Station Crowley, Acadia Parish
227	1	Crowley sil	1973	Rice Experiment Station Crowley, Acadia Parish
228	1	Jeanerette sil	1974	Louis Cramer Farm, Acadia Parish

(x) - Detailed description on the soils can be found in Annual Progress Report Rice Experiment Station Crowley, Louisiana from 1963 to 1974.

(y) - 1 = Coastal Prairie
2 = Mississippi Alluvium South Louisiana
3 = Mississippi Alluvium North Louisiana

(z) - sil = silt loam; c = clay; vfsl = very fine sandy loam; sicl = silty clay loam; fsl = fine sandy loam.

(1) Phosphorus Soluble in Sodium Bicarbonate

Reagents - 0.5 M sodium bicarbonate ($NaHCO_3$) solution for available phosphorus

84.01 g $NaHCO_3$ was dissolved in distilled water and made up to 2 liters. The pH was adjusted to 8.5 with 1M NaOH.

Procedure

A 2.5 g sample of 20 mesh air dry soil was placed into a 6 oz serum bottle. Fifty ml of the extracting solution was added and the bottles shaken for 30 minutes on a mechanical shaker. The contents were filtered through Whatman No.2V folded filter paper. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

(2) Kapp's Texas Buffer for Extracting Available Phosphorus

Reagents - Texas buffered extracting solution for available phosphorus

220 g ammonium acetate ($NH_4C_2H_3O_2$) + 164 ml concentrated hydrochloric acid in distilled water, the pH adjusted to 4.2 ± 0.05 with acetic acid or sodium hydroxide. Then made to 2 liters with distilled water.

Procedure

Fifty ml of the extracting solution was added to 2.5 g soil sample and shaken for 30 minutes on a mechanical shaker. The contents were filtered and the filtrate stored in polyethylene bottles.

(3) Determination of Available Phosphorus in Soil, Bray No.1 Procedure

Reagents - Extracting solution (0.03N NH_4F + 0.025N HCl)

2.22 g NH_4F + 4.31 ml concentrated HCl made up to 2 liters. The extracting solution should be stored in polyethylene bottles.

Procedure

A 2.5 g air-dry, 20 mesh soil sample was weighed into a 6 oz serum bottle. Fifty ml of Bray No.1 extracting solution was added and shaken for 15 minutes on a mechanical shaker. The contents were filtered and the filtrate stored in polyethylene bottles.

(4) Determination of Available Phosphorus in Soil, Bray No.2 Procedure

Reagents - Extracting solution (0.03N NH_4F + 0.1N HCl)

2.22 g NH_4F + 17.24 ml concentrated HCl made

up to 2 liters. The extracting solution should be stored in polyethylene bottles.

Procedure

A 2.5 g sample of 20 mesh air dry soil was placed into a 6 oz serum bottle. Fifty ml of Bray No.2 extracting solution was added and the bottles shaken for 15 minutes on a mechanical shaker. The contents were filtered through Whatman No.2V folded filter paper. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

(5) 0.2N HCl Soluble Phosphorus

Reagents - Extracting solution (0.2N HCl)

34.48 ml concentrated HCl was made up to 2 liters with distilled water to give 0.2N HCl.

Procedure

A 2.5 g sample of 20 mesh air dry soil was placed into a 6 oz serum bottle. Fifty ml of 0.2N HCl extracting solution was added and the bottles shaken for 30 minutes on a mechanical shaker. The contents were filtered through Whatman No.2V folded filter paper. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

(6) Phosphorus Released in Natural Oxidation Condition

Procedure

A 2.5 g air-dry, 20-mesh soil sample was weighed into a 6 oz serum bottle. Then 0.5% ground rice straw was added. Fifty ml of distilled water was added and the bottles sealed with serum caps. The soil-water mixture was exposed to the atmosphere so as to allow the oxygen to be in equilibrium with the soil mixture. The samples were incubated at room temperature for 30 days and shaken occasionally.

After 30 days, the soil mixture was filtered and the filtrate stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

(7) Phosphorus Released in Natural Reduction Alone

Reagents - (a) Distilled water

(b) Nitrogen gas to displace oxygen from the soil-water mixture in the serum bottles.

Procedure

A 2.5 g soil sample which have been ground to pass through a 20-mesh sieve was weighed and placed into a 6 oz serum bottle. Then 0.5% (12.5 mg) ground rice straw was added to each of the 28 soil samples. A total of 50 ml distilled water was added and the bottles sealed with serum

caps. The bottles were purged with nitrogen gas for 10 minutes to get rid of oxygen. This procedure was repeated weekly. The soils were incubated for 30 days at 23°C and shaken occasionally to establish a natural reduction condition.

After 30 days the reduced soil samples were transferred to 100 ml plastic centrifuge tubes and centrifuged at 2000 rpm for 10 minutes. (The purpose of performing this procedure was to facilitate filtering so that the minimum time was allowed for the soil-solution to be exposed to air, therefore the soil will not be reoxidized). The solution was filtered through Whatman No.2V folded filter paper. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

(8) Phosphorus Extracted by Natural Reduction + 0.5M $NaHCO_3$

Reagents - (a) Nitrogen gas

(b) 1.0M $NaHCO_3$

168.02 g $NaHCO_3$ was dissolved in distilled water and made up to 2 liters. The pH was adjusted to 8.5 with 1N NaOH.

Procedure

When the natural reduction has been established, 25 ml of 1.0M $NaHCO_3$ was added into the bottles through the

serum caps. The bottles were shaken for 30 minutes on a mechanical shaker. The contents were centrifuged at 2000 rpm for 10 minutes and then filtered through Whatman No.2V folded filter paper. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca. and Al.

(9) Phosphorus Extracted by Natural Reduction + Kapp's Texas Buffer

Reagents - (a) Nitrogen gas

(b) Double strength Kapp's Texas Buffer extracting solution.

440 g ammonium acetate ($NH_4C_2H_3O_2$) + 328 ml concentrated HCl in distilled water, the pH adjusted to 4.2 ± 0.05 with acetic acid or sodium hydroxide. Then made up to 2 liters with distilled water.

Procedure

After the establishment of the natural reduction condition, 25 ml of double strength Kapp's Texas Buffer extracting solution were injected into the bottles through the serum caps. The bottles were shaken for 30 minutes on a mechanical shaker. The contents were centrifuged at 2000 rpm for 10 minutes and then filtered. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

(10) Phosphorus Extracted by Natural Reduction + Bray No.1

Reagents - (a) Nitrogen gas

(b) Double strength Bray No.1

(0.06N NH_4F + 0.05N HCl)

4.44 g NH_4F + 8.62 ml concentrated HCl made up to 2 liters. The extracting solution should be stored in polyethylene bottles.

Procedure

After the establishment of the natural reduced environment, 25 ml of double strength Bray No.1 extractant were pipeted into the bottles through the serum caps. The bottles were mechanically shaken for 15 minutes. The contents were centrifuged at 2000 rpm for 10 minutes and then filtered. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

(11) Phosphorus Extracted by Natural Reduction + Bray No.2

Reagents - (a) Nitrogen gas

(b) Double strength Bray No.2

(0.06N NH_4F + 0.2N HCl)

4.44 g NH_4F + 34.48 ml concentrated HCl made up to 2 liters with distilled water. The

extracting solution should be stored in polyethylene bottles.

Procedure

After the establishment of the reduced condition, 25 ml of double strength Bray No.2 extractant were injected into the bottles through the serum caps. The bottles were then shaken for 15 minutes on a mechanical shaker. The contents were centrifuged at 2000 rpm for 10 minutes and then filtered. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

(12) Phosphorus Extracted by Natural Reduction + 0.2N HCl

Reagents - (a) Nitrogen gas

(b) 0.4N HCl

68.96 ml concentrated HCl was made up to 2 liters with distilled water to give 0.4N HCl.

Procedure

After the establishment of the natural reduction condition, 25 ml of 0.4N HCl were injected into the bottles through the serum caps. The bottles were shaken for 30 minutes on a mechanical shaker. The contents were centrifuged at 2000 rpm for 10 minutes and then filtered. The filtrate was analyzed for P, Fe, Ca, and Al.

Table 2

Parameters Used in Determination of Inorganic Phosphorus by the Method of Watanabe and Olsen (1965)

No.	Extraction Procedure	Dilution	Aliquot Size (ml)	Range of Standard (ppm P)
1	0.5M $NaHCO_3$	0-5	8	0.1-1.5
2	Kapp's Texas Buffer	0-5	8	0.1-1.5
3	Bray No.1	0-5	5	0.2-2.5
4	Bray No.2	0-10	2	0.5-5.0
5	0.2N HCl	0-10	4	0.2-3.0
6	Natural Oxidized	No	10	0.1-1.0
7	Natural Reduction	0-4	10	0.1-1.0
8	Natural Reduction + 0.5M $NaHCO_3$	0-4	2	0.5-5.0
9	Natural Reduction + Kapp's Texas Buffer	0-10	2	0.5-5.0
10	Natural Reduction + Bray No.1	0-10	2	0.5-5.0
11	Natural Reduction + Bray No.2	0-20	2	0.5-5.0
12	Natural Reduction + 0.2N HCl	0-20	2	0.5-5.0
13	Artificial Reduction (0.1N $Na_2S_2O_4$)	2.5-40	20	0.1-1.0
14	Artificial Reduction (0.2N $Na_2S_2O_4$)	2.5-40	20	0.1-1.0

Table 2 (Continued)

No.	Extraction Procedure	Dilution	Aliquot Size (ml)	Range of Standard (ppm P)
15	Artificial Reduction + 0.5M $NaHCO_3$	2.5-40	20	0.1-1.0
16	Artificial Reduction + Kapp's Texas Buffer	2.5-40	20	0.1-1.0
17	Artificial Reduction + Bray No.1	2.5-40	20	0.1-1.0
18	Artificial Reduction + Bray No.2	2.5-40	20	0.1-1.0
19	Artificial Reduction + 0.2N HCl	2.5-30	20	0.1-1.0
20	Labile P in Natural Oxidized	No	10	0.1-1.0
21	Labile P in Natural Reduction	0-4	10	0.1-1.0
22	Labile P in 0.1N $Na_2S_2O_4$	5-20	20	0.1-1.0
23	Labile P in 0.2N $Na_2S_2O_4$	5-20	20	0.1-1.0

Table 2 (Continued)

No.	Extraction Procedure	Dilution	Aliquot Size (ml)	Range of Standard (ppm P)
24	Inorganic Phosphorus Fraction			
I)	Loosely Bound Phosphorus	No	15	0.1-1.0
II)	Aluminium Phosphate	No	10	0.1-1.5
III)	Iron Phosphate	No	2	0.5-5.0
IV)	Calcium Phosphate	No	5	0.2-2.0
V)	Reductant Soluble Iron Phosphate	No	20	0.1-1.0
VI)	Occuluded Iron and Aluminium Phosphate	No	20	0.1-1.0

Determination of P, Fe, Ca, and Al in the Following Extracts:- (1) 0.5M $NaHCO_3$; (2) Kapp's Texas Buffer; (3) Bray No.1; (4) Bray No.2; (5) 0.2N HCl; (6) Natural Oxidized; (7) Natural Reduction; (8) Natural Reduction + 0.5M $NaHCO_3$; (9) Natural Reduction + Kapp's Texas Buffer; (10) Natural Reduction + Bray No.1; (11) Natural Reduction + Bray No.2; (12) Natural Reduction + 0.2N HCl; (20) Labile Phosphorus in Natural Oxidized Condition; (21) Labile Phosphorus in Natural Reduction; (24) Inorganic Phosphorus Fraction (Steps I,II,III,IV, & VI).

(i) Reagent A: 12 g of ammonium molybdate was dissolved in 250 ml of distilled water and 0.2908 g of antimony potassium tartarate in 100 ml of distilled water. Both were added to 1000 ml of 5N H_2SO_4 (148 ml of concentrated H_2SO_4/liter). They were mixed and made up to 2 liters and stored in pyrex in a cool dark place.

(ii) Reagent B: One gram of ascorbic acid was dissolved in distilled water, 200 ml of reagent A and 500 ml of 2% boric acid were added, mixed thoroughly and made to one liter. Reagent B must be prepared fresh each day.

A known volume of aliquot (as shown in Table 6) from the various extracts was pipeted into 125 ml Erlenmeyer flasks for the analysis of P using the procedure of Watanabe and Olsen (1965). The same procedure was followed for the P

standards. Then 20 ml of reagent B was added to the extracts and standards to develop the blue color. They were read 10 minutes later using a Bausch and Lomb colorimeter (type 33-29-40) set at 800 mu and filtered with a red filter.

The concentration of P in the unknowns was calculated by reading from a graph prepared with standard solutions.

The Fe, Ca, and Al were analyzed using an Atomic Absorption Spectrophotometer (Perkin Elmer model 360).

Phosphorus Released by Artificial Reduction:-

(13) 0.1N $Na_2S_2O_4$

(14) 0.2N $Na_2S_2O_4$

Reagents - (a) 0.1N $Na_2S_2O_4$

34.82 g of $Na_2S_2O_4$ was dissolved in distilled water and made up to 2 liters.

(b) 0.2N $Na_2S_2O_4$

69.64 g of $Na_2S_2O_4$ was dissolved in distilled water and made up to 2 liters.

Procedure

Sodium dithionite ($Na_2S_2O_4$) was used to establish an artificial reduction environment. Two different concentration of $Na_2S_2O_4$ were tested, (a) 0.1N $Na_2S_2O_4$, and (b) 0.2N $Na_2S_2O_4$. The solution was prepared fresh on the day it was to be used.

A 2.5 g soil sample which have been ground to pass through a 20-mesh sieve were weighed and placed into a 6-oz serum bottles. Then 0.5% dextrose (12.5 mg) was added as a source of energy for the soil microbes. A total of 50 ml of 0.1N $Na_2S_2O_4$ was added and the bottles closed with serum caps. The bottles were shaken for one hour on a mechanical shaker after which they were transferred into 100 ml centrifuge tubes and centrifuged at 2000 rpm for 10 minutes. The solution was filtered through Whatman No.2V folded filter paper and the filtrate stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

The same procedure described above was repeated for 0.2N $Na_2S_2O_4$ solution. The purpose of doing this was to investigate which of the two normalities would give a better correlation with percent yield of rice.

(15) Phosphorus Extracted by Artificial Reduction + 0.5M $NaHCO_3$

Reagents - (a) 0.1N $Na_2S_2O_4$

(b) 1.0M $NaHCO_3$

Procedure

After the soil samples have been artificially reduced, 25 ml of 1.0M $NaHCO_3$ was injected into the bottles through the serum caps. The bottles were shaken for 30 minutes on a mechanical shaker. The contents were

transferred into 100 ml plastic centrifuge tubes and centrifuged at 2000 rpm for 10 minutes and then filtered through Whatman No.2V folded filter paper. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

(16) Phosphorus Extracted by Artificial Reduction + Kapp's Texas Buffer

Reagents - (a) 0.1N $Na_2S_2O_4$

(b) Double strength Kapp's Texas Buffer extracting solution

Procedure

After the soil samples have been artificially reduced, 25 ml of double strength Kapp's Texas Buffer extracting solution was injected into the bottles through the serum caps. The bottles were shaken for 30 minutes on a mechanical shaker. The contents were centrifuged at 2000 rpm for 10 minutes and then filtered. The filtrate was analyzed for P, Fe, Ca, and Al.

(17) Phosphorus Extracted by Artificial Reduction + Bray No.1

Reagents - (a) 0.1N $Na_2S_2O_4$

(b) Double Strength Bray No.1

Procedure

After the artificial reduction of the soil samples, 25 ml of double strength Bray No.1 extractant was injected into the bottles through the serum caps and then shaken for 15 minutes on a mechanical shaker. The contents were centrifuged at 2000 rpm for 10 minutes and then filtered through Whatman No.2V folded filter paper. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

(18) Phosphorus Extracted by Artificial Reduction + Bray No.2

Reagents - (a) 0.1N $Na_2S_2O_4$

(b) Double Strength Bray No.2

Procedure

After the soil samples have been artificially reduced, 25 ml of double strength Bray No.2 extractant was injected into the bottles through the serum caps. The bottles were then shaken for 15 minutes on a mechanical shaker. The contents were centrifuged at 2000 rpm for 10 minutes and then filtered through Whatman No.2V folded filter paper. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

(19) Phosphorus Extracted by Artificial Reduction + 0.2N HCl

Reagents - (a) 0.1N $Na_2S_2O_4$

(b) 0.4N HCl

Procedure

After the artificial reduction of the soil samples, 25 ml of 0.4N HCl was injected into the bottles through the serum caps. The bottles were shaken for 30 minutes on a mechanical shaker. Then the contents were centrifuged at 2000 rpm for 10 minutes and then filtered. The filtrate was stored in polyethylene bottles until analyzed for P, Fe, Ca, and Al.

Determination of P, Fe, Ca, and Al in the following Extracts:- (13) 0.1N $Na_2S_2O_4$; (14) 0.2N $Na_2S_2O_4$; (15) Artificial Reduction + 0.5M $NaHCO_3$; (16) Artificial Reduction + Kapp's Texas Buffer; (17) Artificial Reduction + Bray No.1; (18) Artificial Reduction + Bray No.2; (19) Artificial Reduction + 0.2N HCl (22) Labile Phosphorus in 0.1N $Na_2S_2O_4$; (23) Labile Phosphorus in 0.2N $Na_2S_2O_4$; (24) Inorganic Phosphorus Fraction (Step V).

Reagents A and B were prepared as described earlier.

For the determination of P, the sodium dithionite extracts were treated as proposed by Williams et al. (1967). In this investigation, the extracts were diluted with distilled water as shown in Table 6. Then 20 ml of the extracts was pipeted into 125 ml Erlenmeyer flask and left exposed to the atmospheric oxygen for 24 hours to oxidize the excess sodium dithionite so that it would not interfere with the blue color development. The same procedure was followed for the P standards (Table 6).

The P in the extracts and standards were determined by the procedure proposed by Watanabe and Olsen (1965). After the oxidation of the extracts, 20 ml of reagent B was added to develop the blue color. They were read 10 minutes later using a colorimeter (Bausch & Lomb type 33-29-40) set at 800 mu filtered by a red filter.

The concentration of P in the unknowns was calculated by reading from a graph prepared with standard solutions.

A few ml of the diluted extracts were analyzed for Fe, Ca, and Al using an Atomic Absorption Spectrophotometer (Perkin Elmer model 360).

Determination of Labile Phosphorus Under Natural Oxidation, Natural Reduction, and Artificial Reduction

The same soil samples representing 28 soil and year locations of fertilizer response experiments supplied by Dr. D. B. Mengel from Rice Experiment Station Crowley, Louisiana were used.

The radioactive phosphorus was obtained from New England Nuclear, assayed for October 3rd 1977; 25 mCi/ml in 1.0 ml as H_3PO_4 through Dr. R. M. Knaus from Nuclear Science Center, Louisiana State University.

Prediction of ^{32}P Needed for the Experiment

$$A = A_o \times \underset{\text{4 week decay}}{(0.12)} \times \underset{\text{efficiency}}{(0.1)} \times \underset{\text{sample size}}{(1/50)}$$

$$300 = A_o \times (0.12) \times (0.1) \times (0.02)$$

$$300 = A_o \ (0.00024)$$

$$A_o = 300/0.00024$$

$$A_o = 1{,}250{,}000 \text{ dpm}$$

$$= \frac{1.25 \times 10^6}{2.22 \times 10^6} = 0.56 \text{ uCi} \doteq 0.6 \text{ uCi}$$

Therefore 1,250,000 = 0.6 uCi/bottle

150 bottles need 0.6 x 150 = 90 uCi

But, need some ^{32}P for color quenching curve.

Need about 0.2 uCi/bottle

150 bottles need 150 x 0.2 = 30 uCi

Total needed for one experiment = 90 + 30 = 120 uCi

Replicate experiment:

Therefore total ^{32}P needed = 2 x 120 uCi

= 240 uCi or 0.24 mCi

To calculate the dilution needed so that 1 ml will have 0.6 uCi of ^{32}P.

Total = 120 uCi

$\frac{120}{X}$ = 0.6 uCi

Therefore X = 120/0.6 = 200

make up the 120 uCi of ^{32}P to 200 ml of stock solution.

For color quenching curve

The remainder has about 50 ml x 0.6 uCi of ^{32}P

= 30 uCi

The 50 ml containing 30 uCi of ^{32}P was diluted to 3 times.

= 150 ml contains 30 uCi

1 ml = 30/50 = 0.2 uCi of ^{32}P.

In this investigation three treatments were established, namely:

(20) Natural Oxidized Condition,

(21) Natural Reduction,

(22) Artificial Reduction by 0.1N $Na_2S_2O_4$, and

(23) Artificial Reduction by 0.2N $Na_2S_2O_4$.

(20) Labile Phosphorus in Natural Oxidized Condition

A 2.5 g air dry, 20-mesh soil sample was weighed into 6 oz serum bottle. Then 0.5% (12.5 mg) ground rice straw was added to each of the 28 soil samples. A total of 49 ml of distilled water was added and the bottles closed with serum caps. The bottles were exposed to the atmosphere so as to allow the oxygen to diffuse in. The samples were incubated at room temperature for 30 days and shaken occasionally. After 30 days, the samples were ready for the addition of ^{32}P.

(21) Labile Phosphorus in Natural Reduction

A 2.5 g soil sample which have been ground to pass through a 20-mesh sieve was weighed and placed into a 6 oz serum bottle. Then 0.5% (12.5 mg) ground rice straw was added to each of the 28 soil samples. A total of 49 ml distilled water was added and the bottles sealed with serum caps. Nitrogen gas was purged into the bottles for 10

minutes to get rid of the oxygen gas. This procedure was repeated weekly. The soils were incubated for 30 days at room temperature and shaken occasionally, after which they would be ready for the addition of ^{32}P.

Labile Phosphorus in (22) Artificial Reduction by 0.1N $Na_2S_2O_4$; and (23) Artificial Reduction by 0.2N $Na_2S_2O_4$

A 2.5 g air dry, 20-mesh soil sample was weighed into 6 oz serum bottle. Then 0.5% (12.5 mg) dextrose was added. Forty nine ml of 0.1N Na_2S2O_4 which has been freshly prepared was added and the bottles closed with serum caps. The samples were shaken for one hour on a mechanical shaker to establish an artificially reduced environment.

The same procedure was repeated for 0.2N Na_2S2O_4. After the establishment of the artificial reduction, ^{32}P was added to the samples.

Addition of Radioactive Phosphorus into the Natural Oxidation, Natural Reduction, and Artificial Reduction.

Exactly one ml of solution containing 0.34 microcurie of ^{32}P was injected into all the four treatments through the serum caps by using a plastic syringe. The bottles were shaken for 24 hours on a mechanical shaker so that the stable P will be in equilibrium with the ^{32}P. After 24 hours the soil mixtures were centrifuged at 2000 rpm for 15

minutes to seperate the soil particles from the solution. The solution was filtered through Whatman No.2V folded filter paper. The filtrate was stored in polyethylene bottles until analyzed for ^{32}P, stable P, Fe, Ca, and Al. The whole experiment was repeated using 0.60 microcurie of ^{32}P.

Counting the Activity of ^{32}P

Six ml of the filtrate was pipeted for counting the activity of ^{32}P. The radioactive phosphorus was counted by the Cerenkov counting technique in a Beckman Instruments Corp LS-230 liquid scintillation spectrometer using the inner plastic vials devised by Lambremont et al. (1977). Since color quenching will affect the counts, the percent of color quenching was determined. This was achieved by the internal spiking method, whereby a known activity of ^{32}P was injected in all the 112 LS vials. Then the activity of ^{32}P was recounted. The decrease in counts of the added ^{32}P was due to color quenching. The efficiency of the Cerenkov counting was then calculated. The specific activity of the ^{32}P was determined. Knowing all the above factors, the disintergration rate of ^{32}P was then computed. Corrections for radioisotopic decay of ^{32}P was made so that all samples could be compared using the following equation:

$$A_t = A_o e^{-\lambda t}$$

where A_t is the counting rate some time t due to a

radioactive sample that gave counting rate A_o at time t = 0.

Determination of Labile Phosphorus

The labile P of the soils was calculated using the equation used by Talibudeen (1957), and Dalal and Hallsworth (1977).

$$\frac{\text{Surface P}}{\text{Surface } {}^{32}P} = \frac{\text{Solution P}}{\text{Solution } {}^{32}P}$$

where,

Solution P was determined by the procedure of Watanabe and Olsen (1965);

Solution ^{32}P was counted by LS-230 following the procedure of Lambremont et al. (1977);

Surface ^{32}P was obtained by difference.

The surface P was calculated by substituting the above values. The total labile P was obtained by adding the surface P and the solution P. These values obtained will be correlated with the percent yield of rice that has been grown on the soil.

(24) Inorganic Phosphorus Fractionation

Inorganic phosphorus of the soil was fractionated according to the method of Chang and Jackson (1957a).

Principle of the method

(I) Water Soluble and Loosely Bound Phosphorus was determined by extracting one g of soil in 50 ml of 1N NH_4Cl for half an hour and analyzing the extract for orthophosphate.

(II) Aluminum Phosphate was extracted with 50 ml of 0.5N neutral NH_4F. In neutral or alkaline solutions, the fluoride complex of Al is formed but that of iron does not form to any appreciable extent. Neither is calcium phosphate appreciably dissolved in this reagent. Therefore, the phosphate extracted by neutral 0.5N NH_4F is mainly $AlPO_4$ and the method is, therefore, an important step in the soil phosphorus fractionation system.

The F^- ion has the special property of complexing Al^{+3} and Fe^{+3} ions in acid solutions, with consequent release of phosphorus held in the soil by these trivalent ions. The reaction in the acid solution may be represented as follows:

$$3NH_4F + 3HF + AlPO_4 \rightleftharpoons H_3PO_4 + (NH_4)_3AlF_6$$

$$3NH_4F + 3HF + FePO_4 \rightleftharpoons H_3PO_4 + (NH_4)_3FeF_6$$

The fluoroferrate is unstable in neutral or alkaline systems. The $(NH_4)_3AlF_6$ may precipitate with large excess of fluoride. The Fe and Al-P are the hydrated and hydroxyl phosphates including adsorbed or precipitated surface layers on aluminosilicates or oxides. The reaction is not produced when the phosphates are covered by a film of Fe-oxides molecules (occluded phosphates).

(III) Iron Phosphate was extracted with 50 ml of 0.1N NaOH. Strongly alkaline solution such as NaOH has been employed for the extraction of phosphorus from iron phosphate and organic forms of soil phosphorus. The organic P extracted by alkaline solutions is flocculated and excluded from the analysis of the inorganic phosphorus brought into solution. NaOH dissolves synthetic Al and Fe-P compounds but not apatites.

(IV) Calcium Phosphate was extracted with 0.5N H_2SO_4. NH_4F and NaOH treatments should precede the H_2SO_4 treatment since the latter removes considerable aluminum and iron phosphate as well as all the calcium phosphate. H_2SO_4 dissolves all the apatite (up to 3000 ppm P) and dissolves less than half of the Fe and Al-P present.

(V) Reductant Soluble Iron Phosphate is an important fraction of insoluble P which, sometimes, attains as much as 40% of the total P. It has been demonstrated that this fraction can be almost completely extracted by a reduction

process and chelation, this process being essentially specific for the Fe-oxide extractions. The solubilized P was attributed to the occluded forms in the concretioned oxides, protected by coatings of Fe-oxide that covered aggregates and concretions that were resistant to the NaOH and NH_4F, whereas the Fe and Al-P recently precipitated or complexed with humus was largely extracted by the NaOH. The occluded-P forms are almost insoluble and so unavailable for plants.

The soil sample previously extracted in 0.5N H_2SO_4 to remove calcium phosphate was washed twice with 25 ml portions of saturated NaCl solution. It was then suspended in 40 ml of 0.3M sodium citrate solution and 5 ml of M $NaHCO_3$ and the suspension was heated in a water bath at 80°C. Then 1.0 g of $Na_2S_2O_4$ was added with rapid stirring. The suspension was kept at 80°C for 15 minutes and centrifuged. The supernatant solution was collected in a 100 ml volumetric flask. The soil was washed twice with 25 ml portions of saturated NaCl. The two washings being combined with the extract in the 100 ml volumetric flask. The solution in the flask was made to volume and an aliquot of 20 ml was taken for determining P following the procedure of Williams et al. (1967).

A 20 ml aliquot of dithionite citrate extract (Table 6) was placed in 125 ml Erlenmeyer flask and then left exposed to the atmospheric oxygen for 24 hours to oxidize the excess sodium dithionite. After the oxidation of the extract, 20 ml of reagent B was added to the extract and

standards to develop the blue color. They were read 10 minutes later using a colorimeter (Bausch & Lomb type 33-29-40) set at 800 mu filtered by a red filter.

(VI) Occluded Iron and Aluminium Phosphate was extracted with 50 ml of 0.1N NaOH for one hour on a mechanical shaker. The extract was centrifuged at 2000 rpm for 10 minutes and the aliquot was analyzed for P.

(25) Eh and pH of Natural Oxidized Condition

A 2.5 g soil sample which have been ground to pass through a 20-mesh sieve were weighed into a 6 oz serum bottle. Then 0.5% (12.5 mg) ground rice straw was added to each sample. Then 50 ml of distilled water was added and the bottles sealed with air-tight serum caps. The bottles were exposed to the atmosphere so that they would be in equilibrium with the atmospheric oxygen. The soil samples were incubated at room temperature for a 30-day period and hand-shaken occasionally. After 30 days the Eh and pH were measured.

(26) Eh and pH of Natural Reduction Condition

A 2.5 g soil sample was weighed into a 6 oz serum bottle. Then 0.5% (12.5 mg) ground rice straw was added to each sample. Then 50 ml of distilled water was added and the bottles sealed with air-tight serum caps. Nitrogen

gas was flushed into the bottles for 10 minutes to get rid of the oxygen gas so that a reduced condition can be established. The nitrogen gas was flushed in weekly and the bottles hand-shaken occasionally. The soil samples were incubated at room temperature for a 30-day period. Then the Eh and pH were measured.

Eh and pH of Artificial Reduction Caused by:- (27) 0.1N $Na_2S_2O_4$; and (28) 0.2N $Na_2S_2O_4$

A 2.5 g soil sample was weighed into a 6 oz serum bottle. Then 0.5% (12.5 mg) dextrose was added as a source of energy for the soil microbes. A total of 50 ml of 0.1N $Na_2S_2O_4$, freshly prepared was added and shaken for one hour on a mechanical shaker. The Eh and pH of the mixture was measured.

The same procedure mentioned above was repeated for 0.2N $Na_2S_2O_4$. The objective of this was to find the difference between the two normalities of $Na_2S_2O_4$ used.

Eh and pH Measurement

The Eh of the soil samples was measured using platinum and calomel (saturated KCl) electrodes connected to a Beckman model 3500 digital pH meter. Before taking the Eh readings the electrodes were standardized by Quinhydrone dissolved in pH 4.0 buffer. After standardization, the electrodes were immersed into the soil mixture and the Eh value was read directly from the pH meter.

Immediately after that the pH value of the mixture was measured using a Leeds & Northrup model 7411 pH meter.

Statistical Analyses

Statistical analyses were used to obtain the correlation coefficients and regression equations for the relationship between the percent yield of rice to the Phosphorus released by natural reduction, artificial reduction, and extractions by five chemical methods on the above conditions.

RESULT AND DISCUSSION

Percent yield has been used for expressing yield quite extensively by several workers (Bray, 1948; Halstead, 1967; and Cate and Nelson, 1971). The advantage of using percent yield is that the variablity in an experiment could be reduced.

Table 3 showed the yield of rice obtained from different varieties from the years 1963 through 1974, grown on different soil sites. In this investigation, percent yield was calculated using the following equation.

$$\% \text{ yield} = \frac{y^{P}o \times 100}{y^{P}max} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where,

$y^{P}o$ = yield of rice with no P applied but with adequate N and K

$y^{P}max$ = yield of rice with adequate NPK

Phosphorus response in crops is somewhat unique. Unlike nitrogen and potassium, it is neither linear nor simply curvilinear in nature. In this work, apart from making a linear regression of percent yield of rice to soil test phosphorus, quadratic and cubic equations were also tested to find their fit.

Table 3

Yield of Different Varieties of Rice for 28 Soil Sites through the Years 1963 to 1974

Soil Series	Year	Rice Variety	$y-P_o$		$y-P_{max}$		% Yield
			lb/acre	kg/ha	lb/acre	kg/ha	
Midland sil	1963	Bluebonnet 50	4870	5454	4950	5544	98.38
Iberia c	1964	Bluebonnet 50	4300	4816	4530	5074	94.92
Crowley sil	1964	Nato	5250	5880	5440	6093	96.51
Bernard vfsl	1964	Nato	2220	2486	2810	3147	79.00
Harris sil	1964	Nato	4240	4749	4720	5286	89.83
Crowley sil	1964	Nato	1750	1960	4700	5264	37.23
Midland sil	1964	Nato	4670	5230	4980	5578	93.78
Sharkey c	1964	Nato	3850	4312	4340	4861	88.71
Alligator sicl	1965	Bluebonnet 50	5710	6395	5940	6653	96.13
Midland fsl	1965	Saturn	5110	5723	5870	6574	87.05
Harris sil	1965	Saturn	4140	4637	4400	4928	94.09
Crowley sil	1965	Nato	3580	4010	4550	5096	78.68
Midland sil	1965	Nato	4450	4984	4710	5275	94.48
Sharkey c	1965	Nato	3850	4312	4340	4861	88.71
Midland fsl	1966	Saturn	4740	5309	4620	5174	102.60
Crowley sil	1966	Bluebonnet 50	4160	4659	4890	5477	85.07
Patoutville sil	1966	Nato	4670	5230	4990	5589	93.57
Crowley sil	1966	Saturn	3040	3405	5250	5880	57.90

Table 3 (Continued)

Soil Series	Year	Rice Variety	$y-P_o$		$y-P_{max}$		% Yield
			lb/acre	kg/ha	lb/acre	kg/ha	
Midland sil	1966	Saturn	5140	5757	5820	6518	88.32
Midland fsl	1967	Saturn	4310	4827	4880	5466	88.32
Patoutville sil	1967	Nato	4280	4794	4900	5488	87.35
Crowley sil	1971	Vista	3380	3786	5340	5981	63.30
Crowley sil	1971	Starbonnet	3860	4323	5100	5712	75.69
Crowley sil	1972	Vista	3930	4402	5300	5936	74.15
Crowley sil	1972	Starbonnet	4360	4883	5600	6272	77.86
Crowley sil	1973	Vista	4180	4682	5470	6126	76.42
Crowley sil	1973	Starbonnet	4240	4749	5490	6149	77.23
Jeanerette sil	1974	Labelle	3760	4211	3835	4295	98.04

$Y-P_o$ = Yield of rice when no phosphorus is applied, N and K are adequate;
$y-P_{max}$ = Maximum yield of rice when N, P, K are adequate.

Phosphorus Released under Natural Oxidation, Natural Reduction, and Artificial Reduction Conditions

Table 4, 5, 6 and 7 show the values of P released under the above mentioned conditions. The naturally oxidized released from as low as 0.6 ppm to as high as 10.4 ppm P with a mean of 3.8 ppm P. With naturally reduced, the P released ranged from 0.8 ppm to 44.8 ppm with a mean of 10.8 ppm. The amount of P released in the artificially reduced had a greater range of values, from 2.4 ppm to 321.8 ppm. The higher concentration of $Na_2S_2O_4$ had a slightly higher mean of 45.3 ppm compared to 40.8 ppm in the lower concentration. The R^2 values and the regression equations for the above mentioned conditions were given in Table 8 on page 75.

In the naturally oxidized condition all the R^2 were highly significant with the highest R^2 (0.3983**) being for the cubic equation as shown in Table 9.

Under naturally reduced conditions, only the cubic equation had a highly significant R^2 (0.4784**) as shown in Table 9. Both the linear and quadratic equations were significant at the 5% level.

There were no significant coefficient of determinations at both concentrations of artificially reduced conditions (0.1N and 0.2N $Na_2S_2O_4$) when linear regression was used. However, both the R^2s in the quadratic and cubic equations were significant or highly significant. The R^2 in the cubic equations were higher with values of 0.4316** and

Table 4

Equilibrium Soil Solution Phosphorus and Water Soluble Iron, Calcium, and Aluminum Under Naturally Oxidized Condition of Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	6.2	132	16	14
Iberia c	1964	2.1	102	19	45
Crowley sil	1964	5.2	263	13	22
Bernard vfsl	1964	1.6	115	22	40
Harris sil	1964	5.8	315	36	12
Crowley sil	1964	1.7	125	7	351
Midland sil	1964	4.8	68	16	25
Sharkey c	1964	2.8	92	119	172
Alligator sicl	1965	4.8	165	8	312
Midland fsl	1965	5.6	80	17	53
Harris sil	1965	6.0	152	36	37
Crowley sil	1965	0.7	52	37	18
Midland sil	1965	6.0	58	28	15
Sharkey c	1965	1.8	50	128	74
Midland fsl	1966	9.8	68	17	12
Crowley sil	1966	2.2	248	8	198
Patoutville sil	1966	1.6	72	96	20
Crowley sil	1966	1.1	118	6	109
Midland sil	1966	4.7	120	9	40
Midland fsl	1967	10.4	45	21	40
Patoutville sil	1967	1.8	75	10	88
Crowley sil	1971	1.1	80	8	50
Crowley sil	1971	0.6	58	19	86
Crowley sil	1972	1.8	98	11	14
Crowley sil	1972	2.3	128	9	88
Crowley sil	1973	1.2	78	6	72
Crowley sil	1973	1.2	87	9	104
Jeanerette sil	1974	10.4	125	27	274
Mean =		3.8	113	27	85

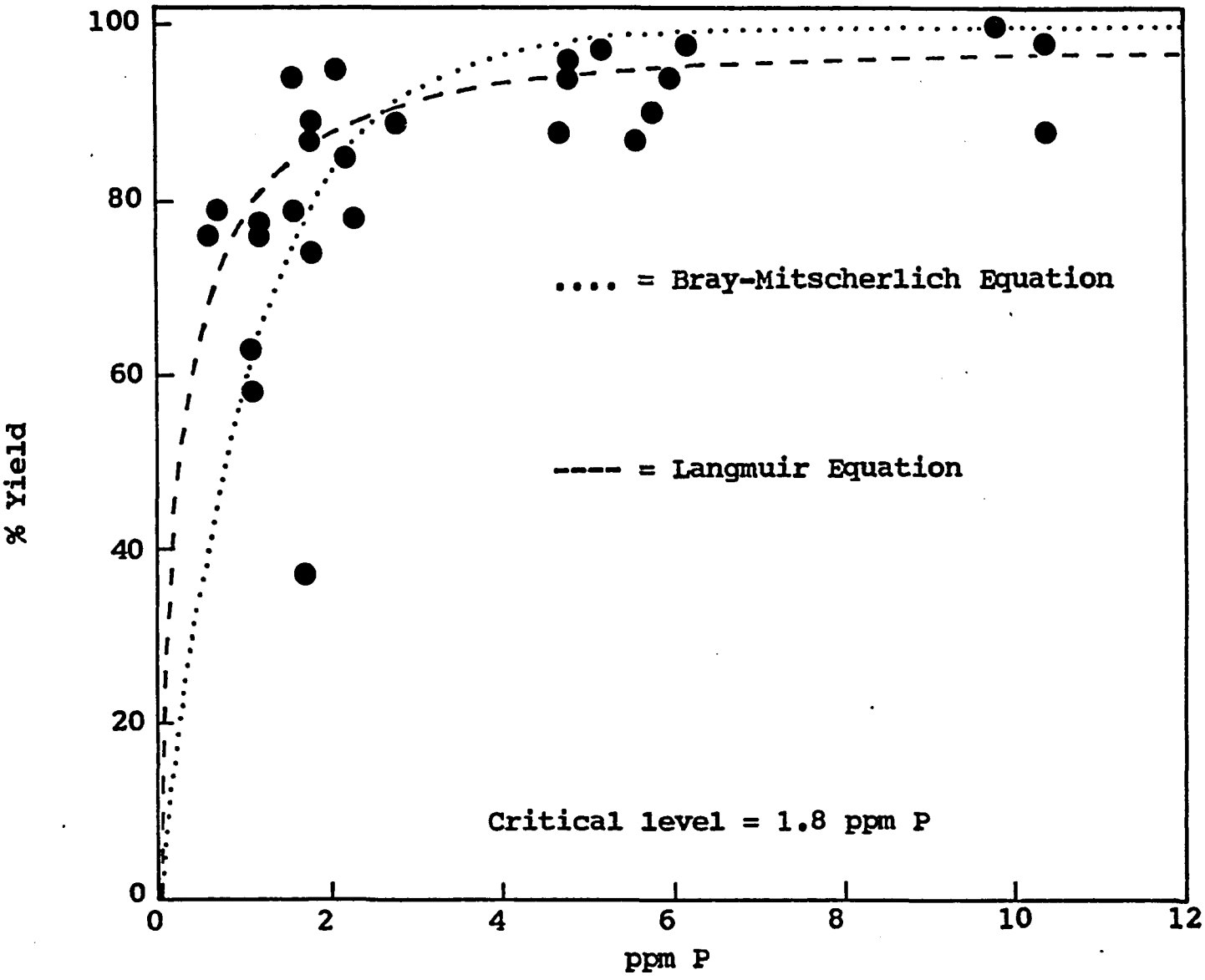

FIGURE 1a. Relationship of % yield of rice to P released under naturally oxidized condition.

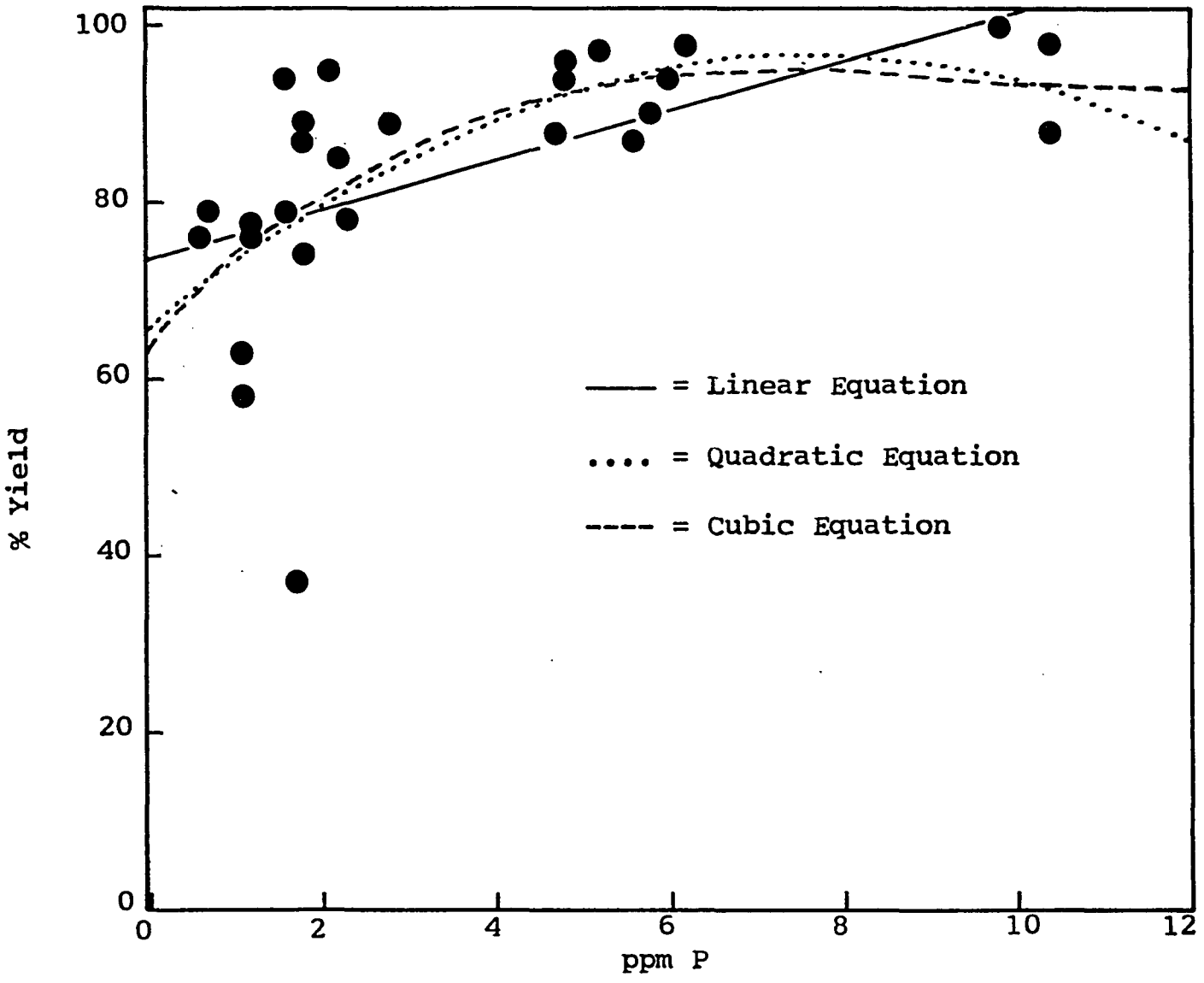

FIGURE 1b. Relationship of % yield of rice to P released under naturally oxidized condition using linear, quadratic, and cubic equations.

Table 5

Equilibrium Soil Solution Phosphorus and Water Soluble Iron, Calcium, and Aluminum Under Naturally Reduced Condition of Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	9.0	150	63	126
Iberia c	1964	4.0	70	320	46
Crowley sil	1964	3.8	300	88	63
Bernard vfsl	1964	2.2	130	106	46
Harris sil	1964	5.4	100	85	51
Crowley sil	1964	0.8	120	310	23
Midland sil	1964	23.8	100	88	46
Sharkey c	1964	44.8	50	610	17
Alligator sicl	1965	12.6	170	125	23
Midland fsl	1965	21.9	120	200	34
Harris sil	1965	7.8	80	81	23
Crowley sil	1965	1.3	130	200	34
Midland sil	1965	18.1	100	93	34
Sharkey c	1965	36.8	50	650	11
Midland fsl	1966	18.7	30	23	23
Crowley sil	1966	3.0	330	35	46
Patoutville sil	1966	1.8	100	400	40
Crowley sil	1966	1.5	150	130	34
Midland sil	1966	7.1	130	81	40
Midland fsl	1967	25.7	90	99	40
Patoutville sil	1967	1.9	120	142	46
Crowley sil	1971	1.2	100	162	34
Crowley sil	1971	1.2	90	210	40
Crowley sil	1972	2.1	80	138	23
Crowley sil	1972	1.7	90	122	34
Crowley sil	1973	1.0	100	152	23
Crowley sil	1973	1.3	100	129	34
Jeanerette sil	1974	41.8	60	72	34
Mean =		10.8	116	176	38

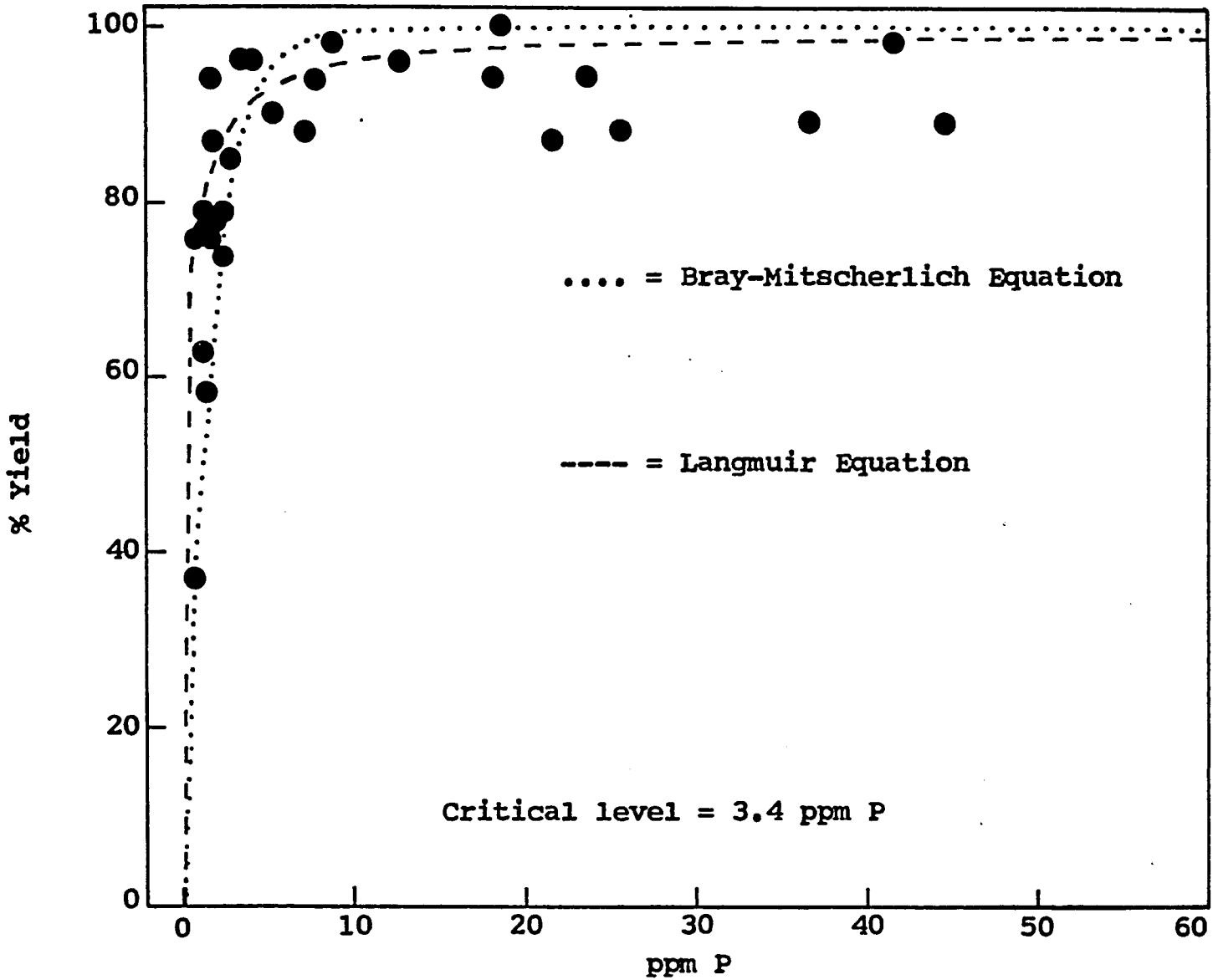

FIGURE 2. Relationship of % yield of rice to P released under naturally reduced condition.

Table 6

Equilibrium Soil Solution Phosphorus and Water Soluble Iron, Calcium, and Aluminum Under Artificially Reduced Condition (0.1N $Na_2S_2O_4$) of Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	28.6	2174	1750	139
Iberia c	1964	22.8	4765	3250	30
Crowley sil	1964	17.6	3428	938	207
Bernard vfsl	1964	9.6	1003	688	304
Harris sil	1964	18.8	2090	1375	300
Crowley sil	1964	2.4	4682	1562	101
Midland sil	1964	50.8	1421	1625	350
Sharkey c	1964	308.2	5936	4000	25
Alligator sicl	1965	69.5	5100	2625	82
Midland fsl	1965	12.0	585	1625	97
Harris sil	1965	26.8	1672	1500	228
Crowley sil	1965	2.4	6688	1625	63
Midland sil	1965	31.8	1547	1875	112
Sharkey c	1965	263.4	5518	4125	21
Midland fsl	1966	16.8	502	1500	106
Crowley sil	1966	13.8	3971	688	312
Patoutville sil	1966	34.7	1588	2500	68
Crowley sil	1966	15.2	2090	2062	95
Midland sil	1966	20.2	1170	2125	68
Midland fsl	1967	12.6	418	2062	65
Patoutville sil	1967	20.2	1547	2125	97
Crowley sil	1971	10.2	1672	2188	93
Crowley sil	1971	10.2	1797	2562	55
Crowley sil	1972	19.6	1672	2000	51
Crowley sil	1972	15.0	1170	2438	49
Crowley sil	1973	11.4	1254	2125	74
Crowley sil	1973	7.8	1087	2125	46
Jeanerette sil	1974	70.2	585	3250	209
Mean =		40.8	2398	2083	123

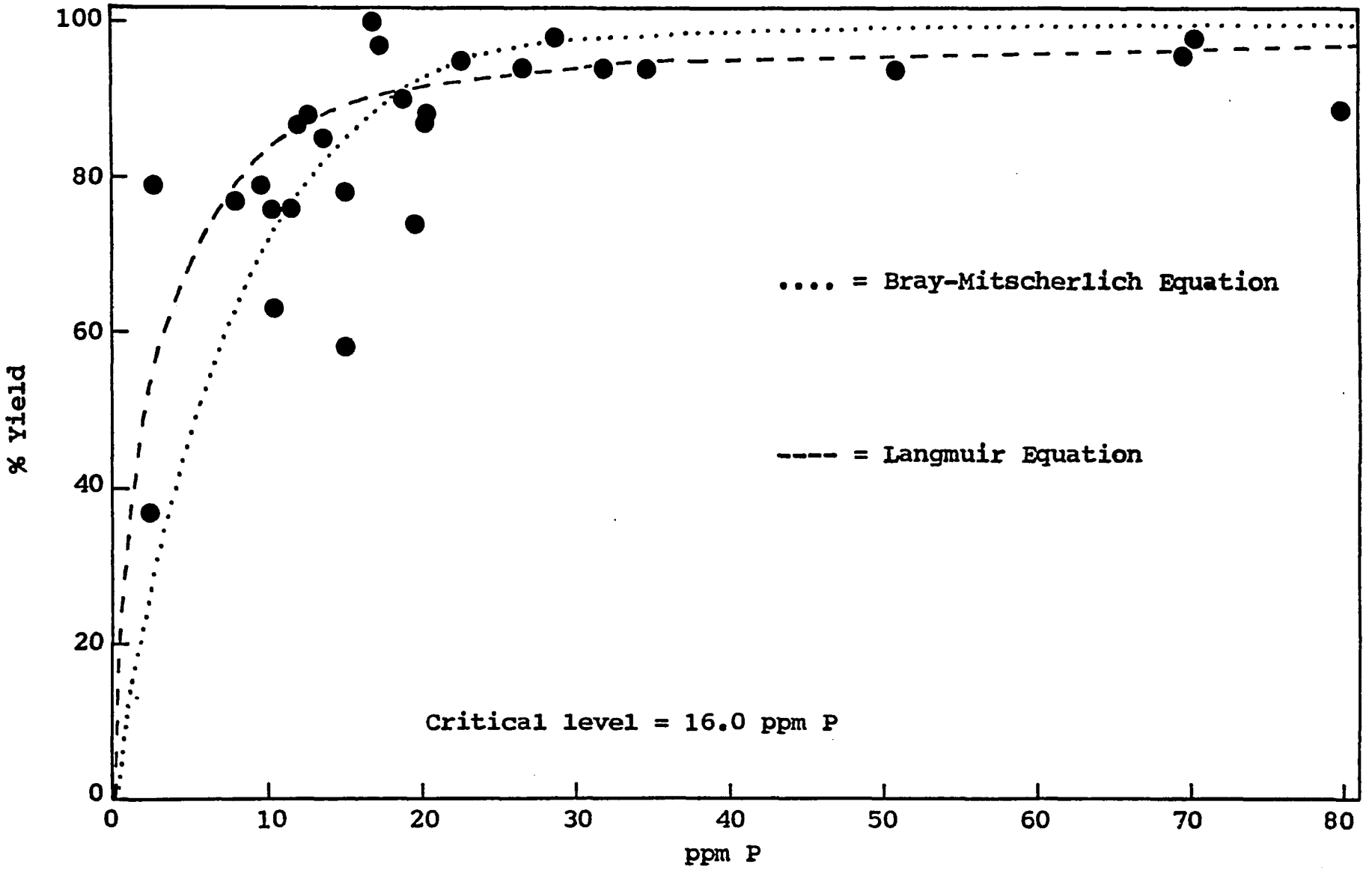

FIGURE 3. Relationship of % yield of rice to P released under artificially reduced (0.1N $Na_2S_2O_4$) condition.

Table 7

Equilibrium Soil Solution Phosphorus and Water Soluble Iron, Calcium, and Aluminum Under Artificially Reduced Condition (0.2N $Na_2S_2O_4$) of Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	28.0	2174	1500	152
Iberia c	1964	29.6	5727	2500	63
Crowley sil	1964	17.7	3469	1062	222
Bernard vfsl	1964	9.6	1003	750	291
Harris sil	1964	18.8	2257	1625	310
Crowley sil	1964	2.8	5225	1625	118
Midland sil	1964	49.0	1505	1750	371
Sharkey c	1964	321.8	6897	3250	46
Alligator sicl	1965	77.2	5894	2188	118
Midland fsl	1965	12.8	585	2250	106
Harris sil	1965	26.0	1672	1500	253
Crowley sil	1965	2.8	4347	2062	112
Midland sil	1965	30.9	1463	2125	181
Sharkey c	1965	314.8	7231	2875	42
Midland fsl	1966	16.2	502	1000	114
Crowley sil	1966	14.8	4473	1250	346
Patoutville sil	1966	24.0	5434	2062	122
Crowley sil	1966	13.9	5810	1562	131
Midland sil	1966	26.7	2090	1625	122
Midland fsl	1967	17.5	502	1625	101
Patoutville sil	1967	7.7	6019	1875	215
Crowley sil	1971	11.1	5559	1938	148
Crowley sil	1971	8.3	5183	1250	169
Crowley sil	1972	27.6	5100	1875	165
Crowley sil	1972	29.5	2842	1375	110
Crowley sil	1973	21.1	3428	1562	118
Crowley sil	1973	15.4	3010	1750	131
Jeanerette sil	1974	93.3	1170	2250	76
Mean =		45.3	3592	1788	159

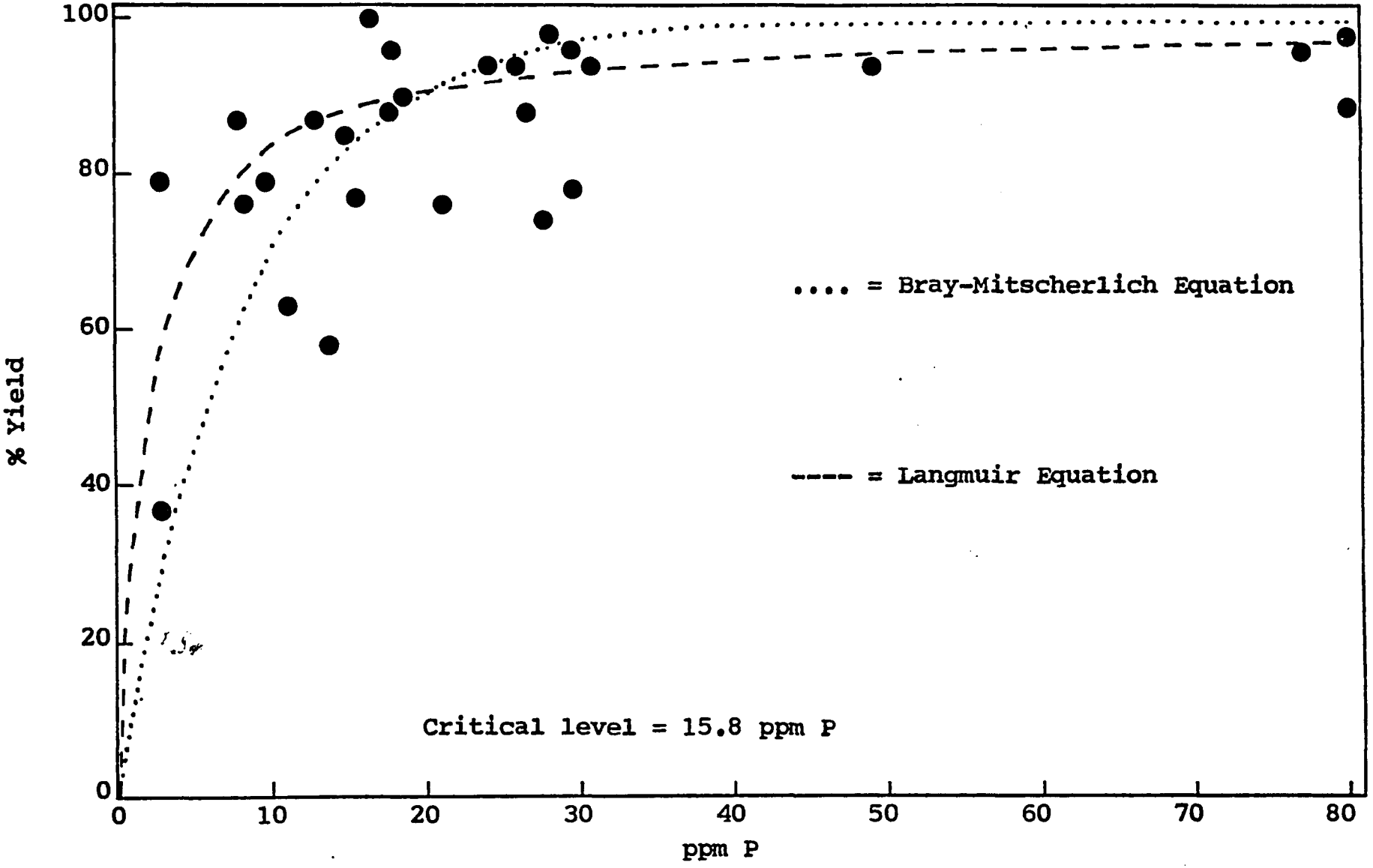

FIGURE 4. Relationship of % yield of rice to P released under artificially reduced (0.2N $Na_2S_2O_4$) condition.

Table 8

Relationship of Percent Yield of Rice and Phosphorus Released Under Natural Oxidation, Natural Reduction, and Artificial Reduction using Linear, Quadratic, and Cubic Equations.

Extraction Procedure	Linear Equation	Quadratic Equation	Cubic Equation
1) Natural Oxidation	$r^2 = 0.2997^{**}$ $\hat{Y} = 73.91 + 2.77X$	$R^2 = 0.3963^{**}$ $\hat{Y} = 65.82 + 7.93X - 0.51X^2$	$R^2 = 0.3983^{**}$ $\hat{Y} = 62.93 + 10.89X - 1.19X^2 + 0.04X^3$
2) Natural Reduction	$r^2 = 0.1749^{*}$ $\hat{Y} = 79.15 + 0.44X$	$R^2 = 0.3142^{*}$ $\hat{Y} = 74.40 + 1.81X - 0.03X^2$	$R^2 = 0.4784^{**}$ $\hat{Y} = 66.87 + 5.50X - 0.28X^2 + 0.004X^3$
3) Artificial Reduction (0.1N $Na_2S_2O_4$)	$r^2 = 0.0561$ $\hat{Y} = 81.84 + 0.045X$	$R^2 = 0.3426^{**}$ $\hat{Y} = 72.20 + 0.56X - 0.002X^2$	$R^2 = 0.4316^{**}$ $\hat{Y} = 67.70 + 0.91X - 0.006X^2 + 0.00001X^3$
4) Artificial Reduction (0.2N $Na_2S_2O_4$)	$r^2 = 0.0514$ $\hat{Y} = 81.93 + 0.039X$	$R^2 = 0.3032^{*}$ $\hat{Y} = 72.58 + 0.497X - 0.001X^2$	$R^2 = 0.3951^{**}$ $\hat{Y} = 64.12 + 1.19X - 0.01X^2 + 0.00002X^2$

(* = significant at 5% level

** = highly significant at 1% level)

0.3951** for 0.1N and 0.2N $Na_2S_2O_4$ respectively. The 0.1N $Na_2S_2O_4$ extracted P somewhat better in predicting rice yield than was the higher concentration.

Various Chemical Extractions of P from the (i) Air-Dried, (ii) Naturally Reduced, and (iii) Artificially Reduced (0.1N $Na_2S_2O_4$) Soils.

(i) Chemical Extractions of P from Oxidized (Air-Dried) Soils.

Among the five chemical extractants used (0.5M $NaHCO_3$, Kapp's Texas Buffer, Bray No.1, Bray No.2, and 0.2N HCl), to extract P in the air-dried soils, Kapp's Texas Buffer was the weakest extractant with a mean of 7.2 ppm P (Table 10) while Bray No.2 was the strongest extractant with a mean of 37.5 ppm P (Table 12). The other three extractants, 0.5M $NaHCO_3$, Bray No.1, and 0.2N HCl were intermediary with means of 8.2, 18.2, and 30.7 ppm P respectively (Tables 9, 11, and 13).

Bray No.1 was the only extractant that gave a significant linear coefficient of determinations (r^2 = 0.2093*). The r^2 and the regression equation was given in Table 24 on page 110.

When the quadratic equation was used, the ranking of the R^2 from the highest to the lowest was as follows: Bray No.1 > Kapp's Texas Buffer > Bray No.2 > 0.5M $NaHCO_3$ > 0.2N

Table 9

Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils by 0.5M $NaHCO_3$ - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	4.5	22	543	11
Iberia c	1964	7.9	17	724	11
Crowley sil	1964	4.1	39	634	11
Bernard vfsl	1964	7.9	104	814	125
Harris sil	1964	7.2	82	814	49
Crowley sil	1964	3.4	35	905	11
Midland sil	1964	9.2	52	905	11
Sharkey c	1964	29.0	56	724	22
Alligator sicl	1965	11.6	65	1629	16
Midland fsl	1965	5.4	69	996	16
Harris sil	1965	7.9	73	1629	27
Crowley sil	1965	2.4	43	996	11
Midland sil	1965	6.6	60	905	11
Sharkey c	1965	32.9	69	1086	11
Midland fsl	1966	9.9	91	1176	22
Crowley sil	1966	5.4	78	543	22
Patoutville sil	1966	11.6	52	634	11
Crowley sil	1966	2.9	48	634	16
Midland sil	1966	4.7	60	814	11
Midland fsl	1967	11.3	95	996	22
Patoutville sil	1967	7.5	60	905	16
Crowley sil	1971	2.8	52	814	22
Crowley sil	1971	2.2	60	905	33
Crowley sil	1972	4.1	48	996	33
Crowley sil	1972	4.5	56	543	33
Crowley sil	1973	2.9	56	996	33
Crowley sil	1973	2.0	73	1086	33
Jeanerette sil	1974	18.2	78	1358	38
Mean =		8.2	60	918	25

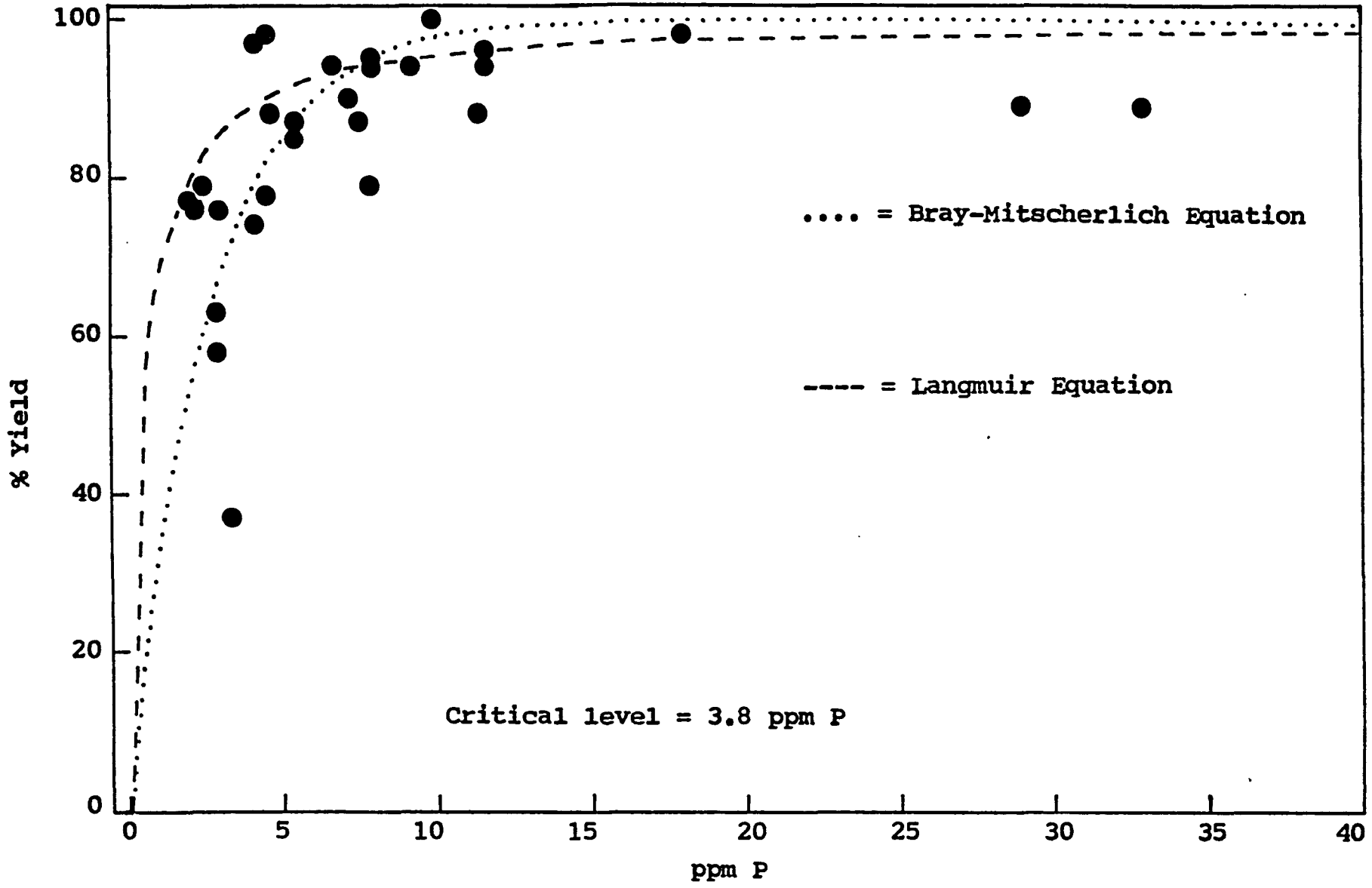

FIGURE 5. Relationship of % yield of rice to P extracted by 0.5M $NaHCO_3$ in air-dried soils.

Table 10

Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils by Kapp's Texas Buffer - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	4.8	99	2353	22
Iberia c	1964	8.0	62	8688	33
Crowley sil	1964	2.8	112	1176	43
Bernard vfsl	1964	3.2	149	362	244
Harris sil	1964	3.2	273	1086	244
Crowley sil	1964	1.1	87	2715	33
Midland sil	1964	9.3	87	3710	22
Sharkey c	1964	33.2	112	9774	65
Alligator sicl	1965	5.9	198	3892	130
Midland fsl	1965	4.9	99	1900	38
Harris sil	1965	4.9	186	2715	157
Crowley sil	1965	1.7	105	1810	49
Midland sil	1965	6.3	112	3077	33
Sharkey c	1965	31.3	124	9684	70
Midland fsl	1966	7.3	136	905	65
Crowley sil	1966	3.1	198	814	173
Patoutville sil	1966	12.8	136	3982	54
Crowley sil	1966	1.7	112	1991	43
Midland sil	1966	3.5	118	2353	38
Midland fsl	1967	7.7	124	814	60
Patoutville sil	1967	4.1	112	2715	70
Crowley sil	1971	1.1	149	1448	49
Crowley sil	1971	2.9	143	1900	54
Crowley sil	1972	2.9	118	1900	38
Crowley sil	1972	2.4	118	1810	43
Crowley sil	1973	1.5	124	1900	43
Crowley sil	1973	1.6	124	1448	49
Jeanerette sil	1974	28.2	118	4163	38
Mean =		7.2	130	2896	71

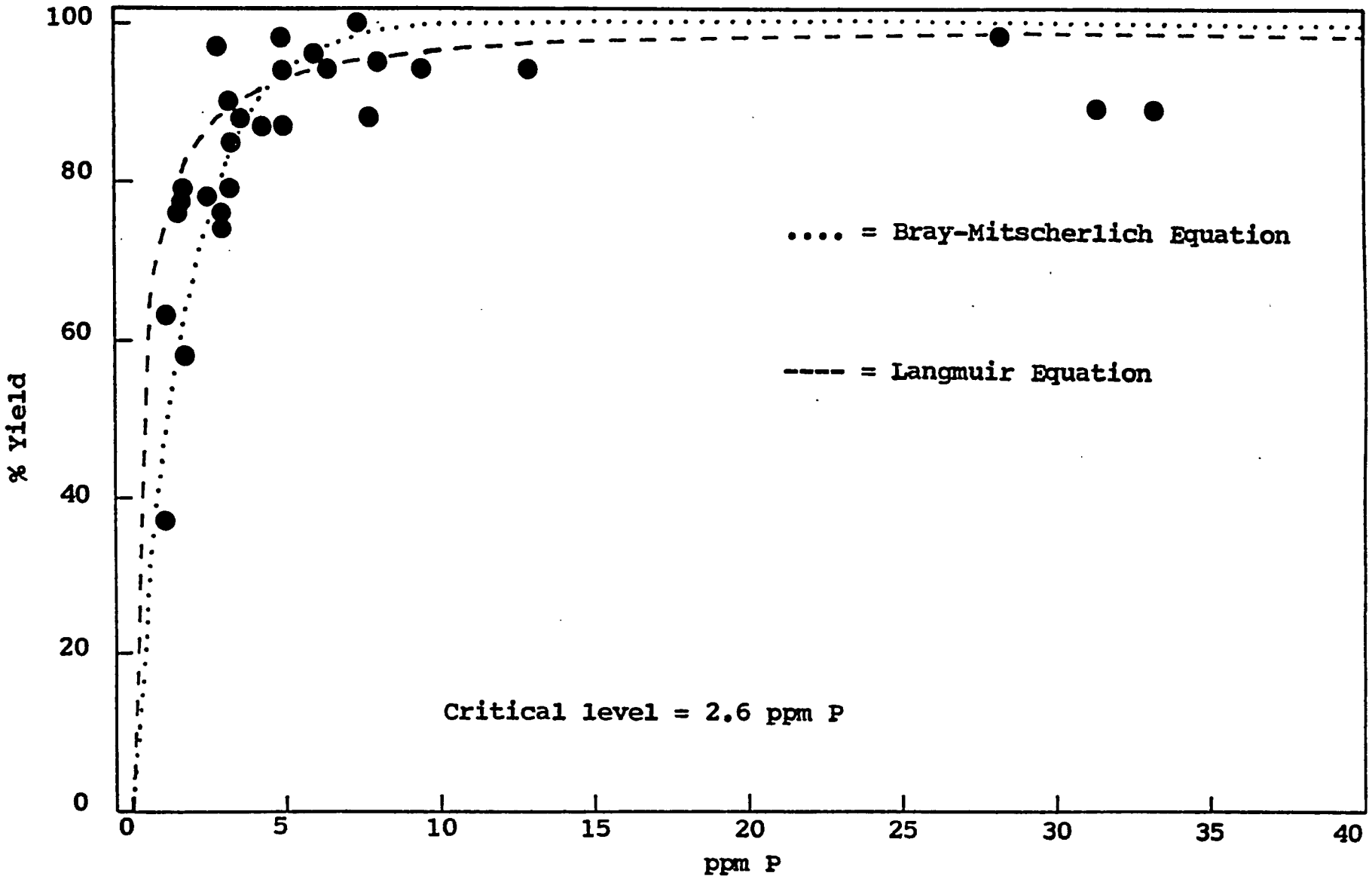

FIGURE 6. Relationship of % yield of rice to P extracted by Kapp's Texas Buffer in air-dried soils.

Table 11

Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils by Bray No.1 - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	13.9	589	1176	1281
Iberia c	1964	19.3	87	724	1482
Crowley sil	1964	8.6	533	996	1482
Bernard vfsl	1964	15.2	304	543	1934
Harris sil	1964	17.1	450	1448	2311
Crowley sil	1964	2.5	254	1448	1683
Midland sil	1964	27.6	453	2172	1156
Sharkey c	1964	70.1	304	1448	678
Alligator sicl	1965	26.5	521	1176	2160
Midland fsl	1965	11.5	267	1267	1030
Harris sil	1965	27.2	422	1358	1784
Crowley sil	1965	4.3	384	1176	1633
Midland sil	1965	17.1	384	1538	1181
Sharkey c	1965	63.9	298	1538	1017
Midland fsl	1966	17.4	236	814	955
Crowley sil	1966	9.5	583	724	1557
Patoutville sil	1966	18.2	415	1448	1683
Crowley sil	1966	3.9	583	1086	1231
Midland sil	1966	10.9	450	1991	1206
Midland fsl	1967	15.5	236	996	829
Patoutville sil	1967	13.3	186	1267	1984
Crowley sil	1971	3.6	918	1086	1281
Crowley sil	1971	3.7	744	1267	1382
Crowley sil	1972	7.1	707	1358	1156
Crowley sil	1972	6.5	670	1810	1256
Crowley sil	1973	3.4	601	1267	1231
Crowley sil	1973	3.0	570	1538	1306
Jeanerette sil	1974	69.6	608	2624	791
Mean =		18.2	456	1332	1381

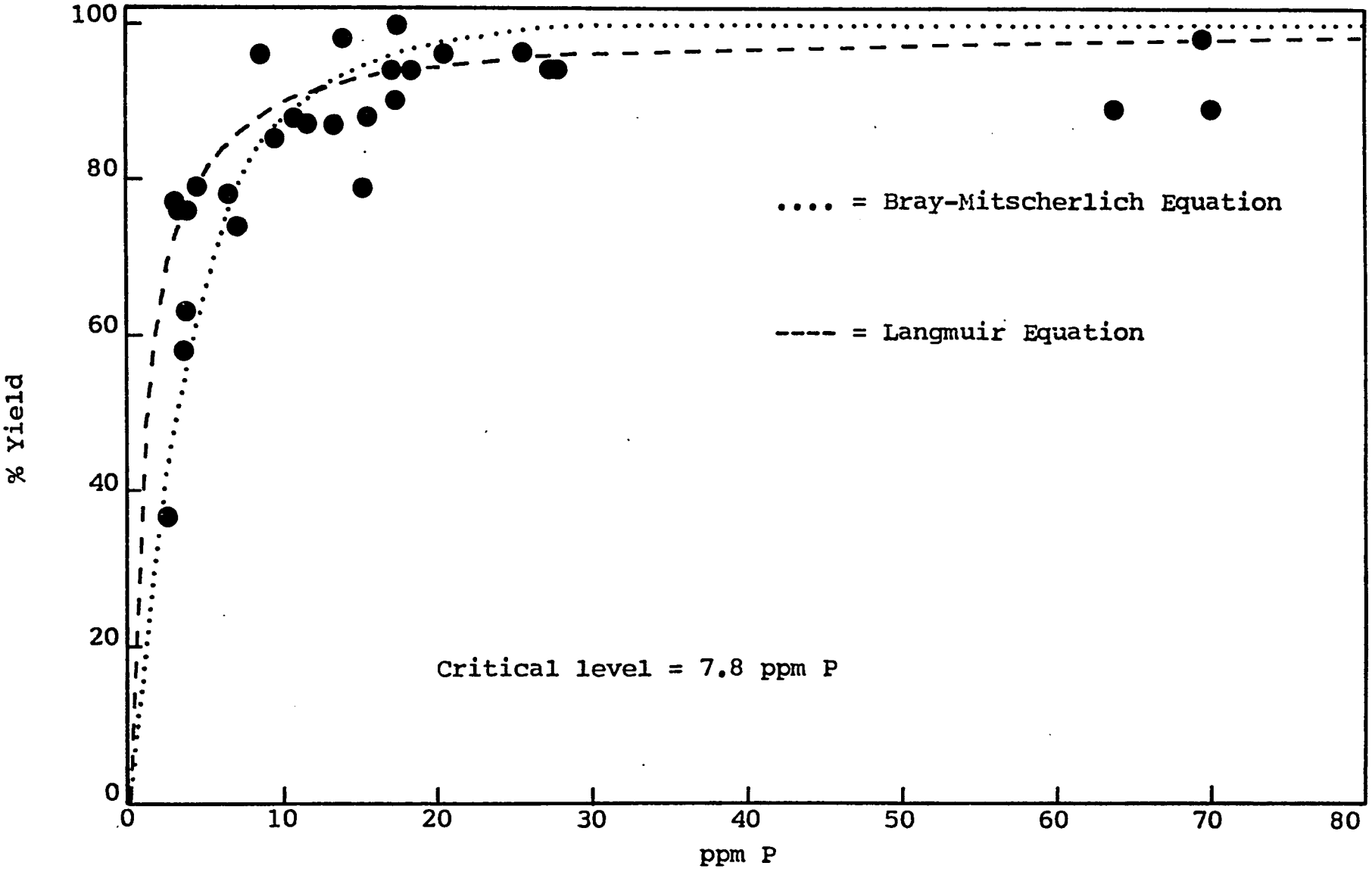

FIGURE 7a. Relationship of % yield of rice to P extracted by Bray No.1 in air-dried soils.

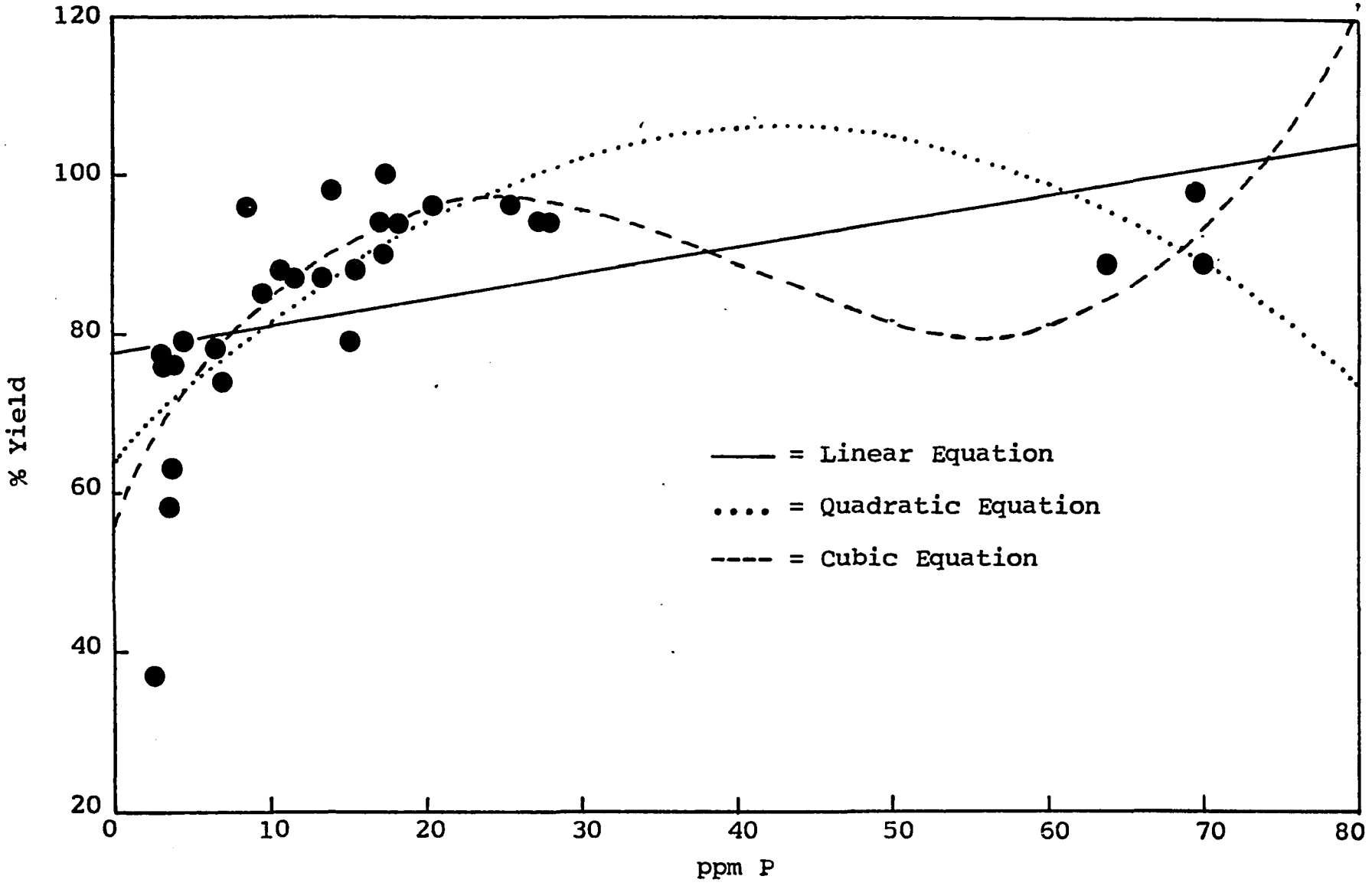

FIGURE 7b. Relationship of % yield of rice to P extracted by Bray No.1 in air-dried soils using linear, quadratic, and cubic equations.

Table 12

Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils by Bray No.2 - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	22.7	1024	2000	1762
Iberia c	1964	46.3	773	2750	3577
Crowley sil	1964	12.6	836	1750	1734
Bernard vfsl	1964	16.3	502	1438	1816
Harris sil	1964	28.3	1212	1750	2764
Crowley sil	1964	4.5	627	1500	2276
Midland sil	1964	46.1	794	2125	1599
Sharkey c	1964	235.6	2299	4250	2873
Alligator sicl	1965	67.2	1588	2375	2764
Midland fsl	1965	14.5	418	1875	1192
Harris sil	1965	38.0	836	1750	2222
Crowley sil	1965	8.0	878	1062	2141
Midland sil	1965	26.4	690	1938	1653
Sharkey c	1965	209.8	2341	3812	2981
Midland fsl	1966	20.4	711	1438	1138
Crowley sil	1966	12.8	752	1375	1626
Patoutville sil	1966	37.6	1150	2125	2304
Crowley sil	1966	7.4	961	1750	1653
Midland sil	1966	16.7	752	2125	1518
Midland fsl	1967	17.6	230	1875	948
Patoutville sil	1967	19.6	543	1000	2764
Crowley sil	1971	8.0	1463	938	1762
Crowley sil	1971	7.8	1233	1875	1897
Crowley sil	1972	13.2	1170	2000	1518
Crowley sil	1972	11.6	1212	2375	1789
Crowley sil	1973	6.2	1003	2000	1626
Crowley sil	1973	5.8	940	1000	1653
Jeanerette sil	1974	89.8	1066	3125	1355
Mean =		37.5	1000	1978	1961

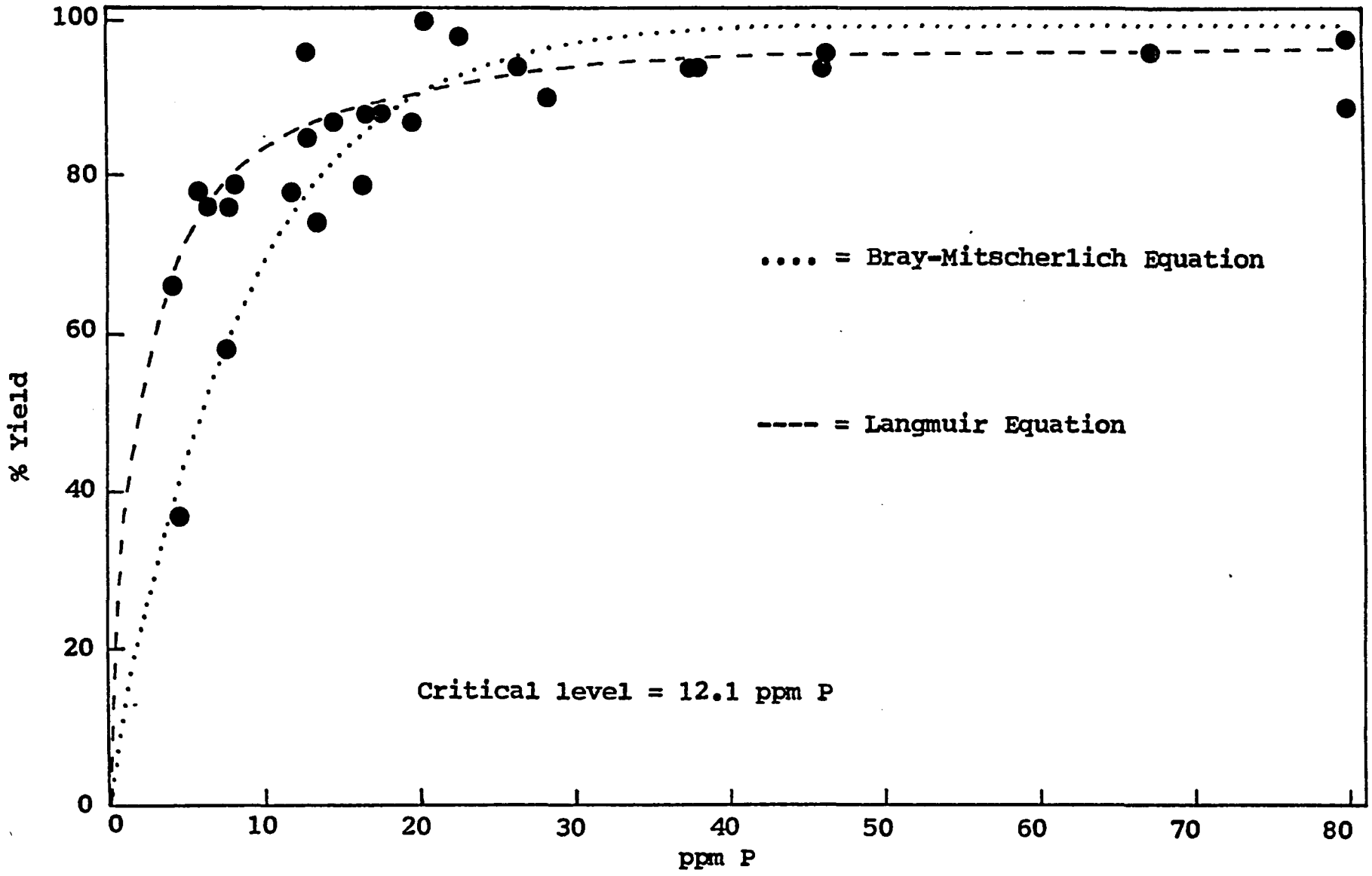

FIGURE 8. Relationship of % yield of rice to P extracted by Bray No.2 in air-dried soils.

Table 13

Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils by 0.2N HCl - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	12.3	376	2082	282
Iberia c	1964	42.8	293	7330	970
Crowley sil	1964	5.8	251	1720	211
Bernard vfsl	1964	11.8	272	634	726
Harris sil	1964	16.7	878	2353	916
Crowley sil	1964	1.3	167	1900	369
Midland sil	1964	32.3	251	2896	298
Sharkey c	1964	240.8	1505	8778	1030
Alligator sicl	1965	43.5	794	3710	661
Midland fsl	1965	10.0	188	1900	195
Harris sil	1965	24.1	648	1720	618
Crowley sil	1965	2.7	230	2444	325
Midland sil	1965	16.7	230	2624	298
Sharkey c	1965	220.8	1547	8598	1073
Midland fsl	1966	14.5	188	996	195
Crowley sil	1966	6.9	334	634	304
Patoutville sil	1966	19.6	585	2896	401
Crowley sil	1966	2.7	251	2262	271
Midland sil	1966	9.1	293	2262	293
Midland fsl	1967	13.6	167	1176	173
Patoutville sil	1967	7.8	293	2172	369
Crowley sil	1971	2.7	460	2082	304
Crowley sil	1971	2.5	439	2262	320
Crowley sil	1972	4.9	334	1900	271
Crowley sil	1972	4.9	376	2262	314
Crowley sil	1973	2.7	251	1720	271
Crowley sil	1973	2.5	272	1900	271
Jeanerette sil	1974	83.6	585	4254	336
Mean =		30.7	445	2767	431

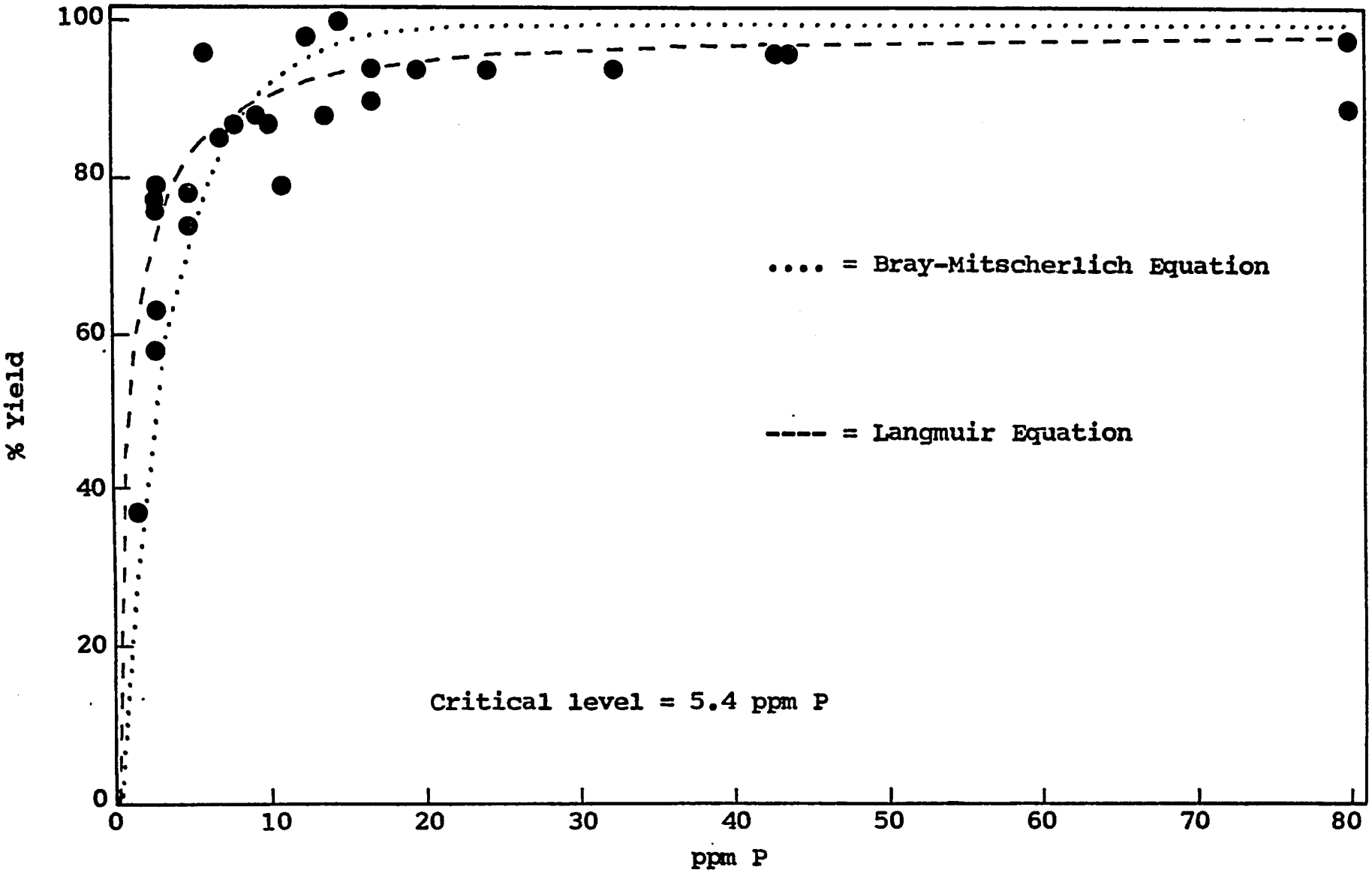

FIGURE 9. Relationship of % yield of rice to P extracted by 0.2N HCl in air-dried soils.

HCl (Table 24). The R^2 in all the five extractants were highly significant. The quadratic equation of the Bray No.1 was:

$$\hat{Y} = 63.67 + 1.97X - 0.023X^2$$

having an R^2 value of 0.5549**. When the cubic equation was used, the ranking according the R^2 remained the same while the R^2 value increased in all extractants. The highest R^2 was found in the Bray No.1 with an R^2 of 0.6401** and regression equation of:

$$\hat{Y} = 54.89 + 4.04X - 0.12X^2 + 0.001X^3$$

(ii) Chemical Extraction of P from the Naturally Reduced Soils.

Reducing the soils naturally and then extracting them by the chemical methods changed the rankings a little. The ranking of the R^2 using the quadratic equation in a decending order was as follows: Naturally reduced + 0.5M $NaHCO_3$ > naturally reduced + Bray No.1 > naturally reduced + Bray No.2 > naturally reduced + 0.2N HCl > naturally reduced + Kapp's Texas Buffer. The R^2 value in the case of the 0.5M $NaHCO_3$ was 0.5390** and the regression equation was:

$$\hat{Y} = 60.16 + 1.93X - 0.02X^2$$

When the cubic equation was used, the highest R^2 was still observed in the naturally reduced + 0.5M $NaHCO_3$ with value of 0.5975** followed by naturally reduced + 0.2N HCl with R^2 value of 0.5634**. The naturally reduced + Bray

Table 14

Effect of Natural Reduction + 0.5M $NaHCO_3$ on Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	16.2	196	2444	25
Iberia c	1964	17.4	176	1629	23
Crowley sil	1964	9.4	213	1991	25
Bernard vfsl	1964	12.3	142	1538	116
Harris sil	1964	15.7	209	1991	30
Crowley sil	1964	2.1	67	1720	23
Midland sil	1964	30.2	134	1900	25
Sharkey c	1964	76.5	167	2172	23
Alligator sicl	1965	51.0	242	2353	25
Midland fsl	1965	15.3	92	1629	55
Harris sil	1965	19.1	201	1810	42
Crowley sil	1965	7.2	117	1448	32
Midland sil	1965	23.0	150	1086	25
Sharkey c	1965	76.5	130	1629	25
Midland fsl	1966	17.4	176	1448	25
Crowley sil	1966	7.2	230	2353	25
Patoutville sil	1966	29.8	75	1720	30
Crowley sil	1966	7.2	146	1720	25
Midland sil	1966	15.7	217	1086	23
Midland fsl	1967	17.4	113	1720	30
Patoutville sil	1967	19.1	96	1538	38
Crowley sil	1971	7.2	100	1448	25
Crowley sil	1971	4.2	88	1810	25
Crowley sil	1972	12.3	150	2353	25
Crowley sil	1972	11.0	142	2082	23
Crowley sil	1973	15.3	100	2082	25
Crowley sil	1973	5.5	142	1900	25
Jeanerette sil	1974	73.1	84	2082	25
Mean =		21.9	146	1810	31

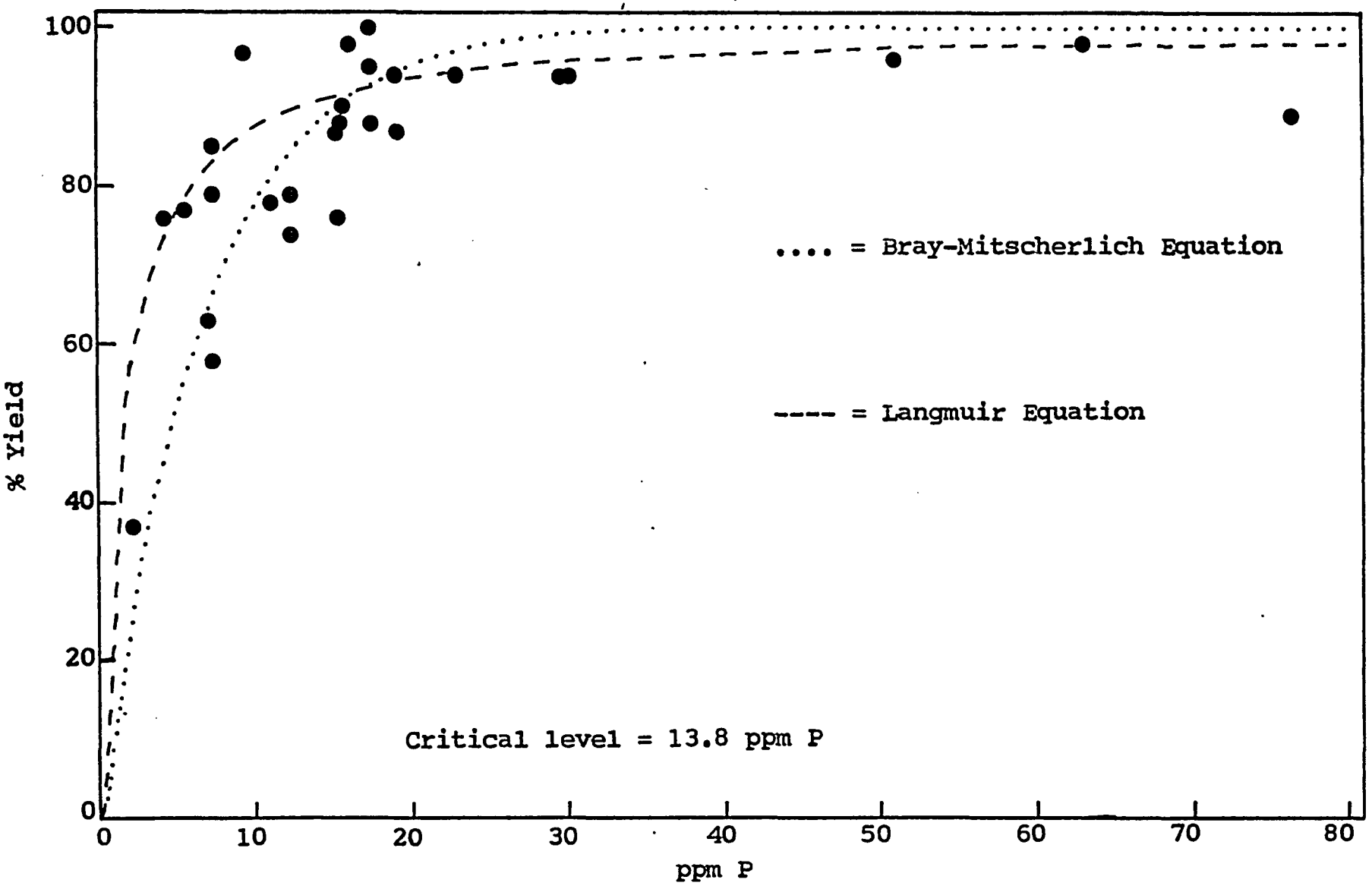

FIGURE 10. Relationship of % yield of rice to P extracted by natural reduction + 0.5M $NaHCO_3$.

Table 15

Effect of Natural Reduction + Kapp's Texas Buffer on Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils -ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	32.8	1200	2550	29
Iberia c	1964	43.8	2260	8200	69
Crowley sil	1964	20.3	1360	1025	69
Bernard vfsl	1964	7.0	550	375	286
Harris sil	1964	16.1	1540	1030	149
Crowley sil	1964	5.4	1300	2400	69
Midland sil	1964	54.9	720	3075	23
Sharkey c	1964	283.7	5700	8800	63
Alligator sicl	1965	98.6	3400	4775	126
Midland fsl	1965	24.6	380	1750	23
Harris sil	1965	23.6	700	2150	91
Crowley sil	1965	11.5	1620	1975	126
Midland sil	1965	41.9	660	3125	23
Sharkey c	1965	249.4	5600	9980	69
Midland fsl	1966	24.6	310	875	46
Crowley sil	1966	13.3	1060	525	103
Patoutville sil	1966	43.2	2020	3675	80
Crowley sil	1966	15.5	1960	1750	69
Midland sil	1966	34.2	1200	2625	34
Midland fsl	1967	26.8	240	825	34
Patoutville sil	1967	24.6	1720	1950	86
Crowley sil	1971	14.7	1900	1950	80
Crowley sil	1971	10.7	1760	2175	91
Crowley sil	1972	28.2	1800	1950	57
Crowley sil	1972	23.7	1900	2350	63
Crowley sil	1973	15.9	1800	1800	69
Crowley sil	1973	13.5	1760	1625	69
Jeanerette sil	1974	110.6	950	4600	11
Mean =		46.9	1692	2853	75

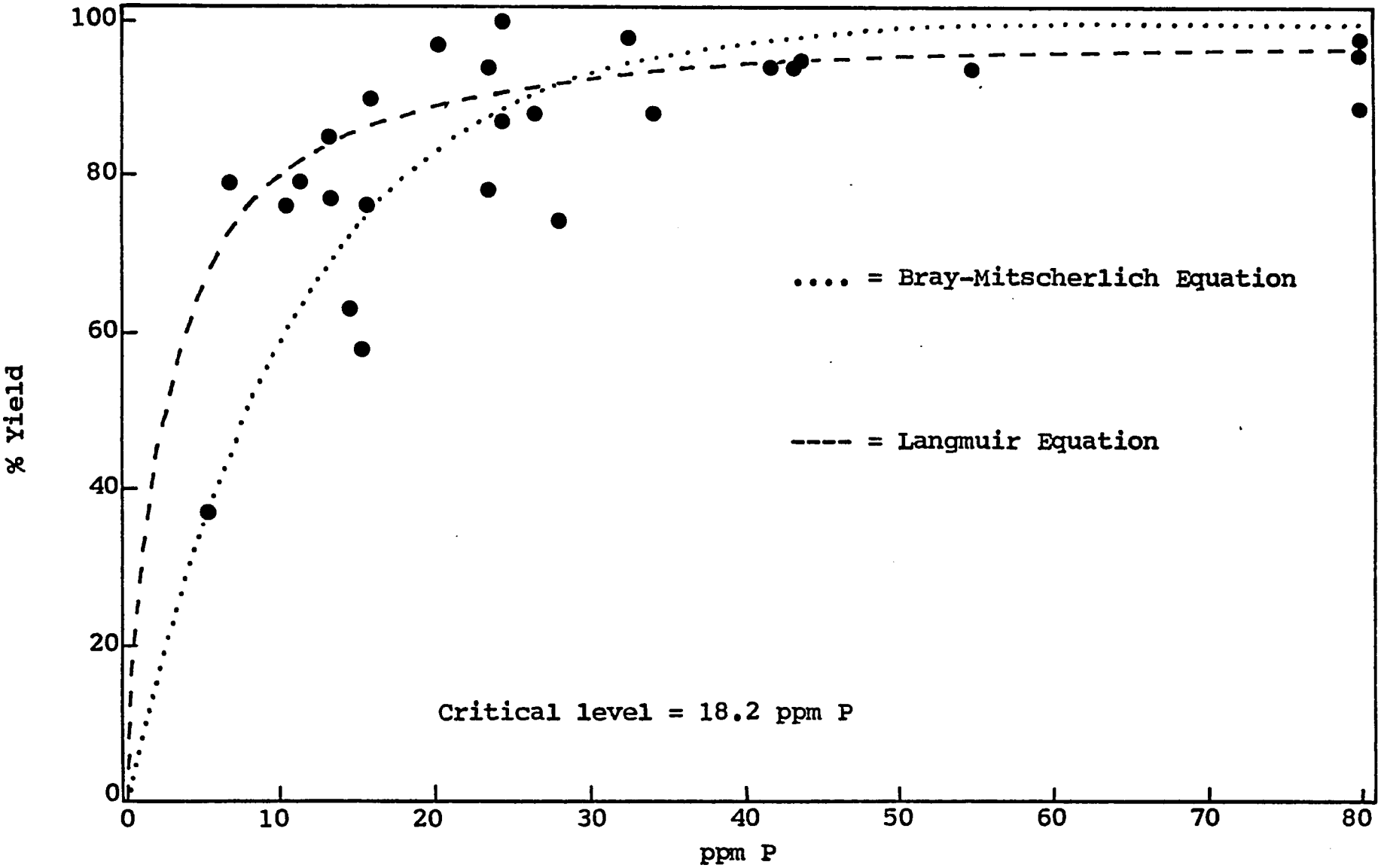

FIGURE 11. Relationship of % yield of rice to P extracted by natural reduction + Kapp's Texas Buffer.

Table 16

Effect of Natural Reduction + Bray No.1 on Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	45.0	1953	1750	1228
Iberia c	1964	72.9	2877	375	882
Crowley sil	1964	32.4	2194	1250	1181
Bernard vfsl	1964	34.8	670	438	1606
Harris sil	1964	62.0	1618	1062	2150
Crowley sil	1964	16.6	2138	1062	1725
Midland sil	1964	73.7	1538	1875	1218
Sharkey c	1964	315.9	3224	1188	315
Alligator sicl	1965	172.1	4371	812	1260
Midland fsl	1965	35.2	670	1562	945
Harris sil	1965	62.8	1088	1250	2552
Crowley sil	1965	24.3	3128	1000	1418
Midland sil	1965	52.6	1451	1812	1701
Sharkey c	1965	283.5	3348	1000	210
Midland fsl	1966	38.9	502	1375	874
Crowley sil	1966	33.6	2595	1000	1394
Patoutville sil	1966	68.9	2877	875	1071
Crowley sil	1966	26.3	3181	1375	874
Midland sil	1966	47.4	2065	1938	945
Midland fsl	1967	37.7	558	1562	662
Patoutville sil	1967	56.7	2877	1375	1617
Crowley sil	1971	27.9	3174	1188	638
Crowley sil	1971	22.7	2930	1188	638
Crowley sil	1972	44.1	2790	1562	378
Crowley sil	1972	38.9	3460	1500	496
Crowley sil	1973	25.5	3069	1375	520
Crowley sil	1973	23.9	3097	2000	803
Jeanerette sil	1974	119.5	1736	2062	788
Mean =		67.7	2328	1315	1075

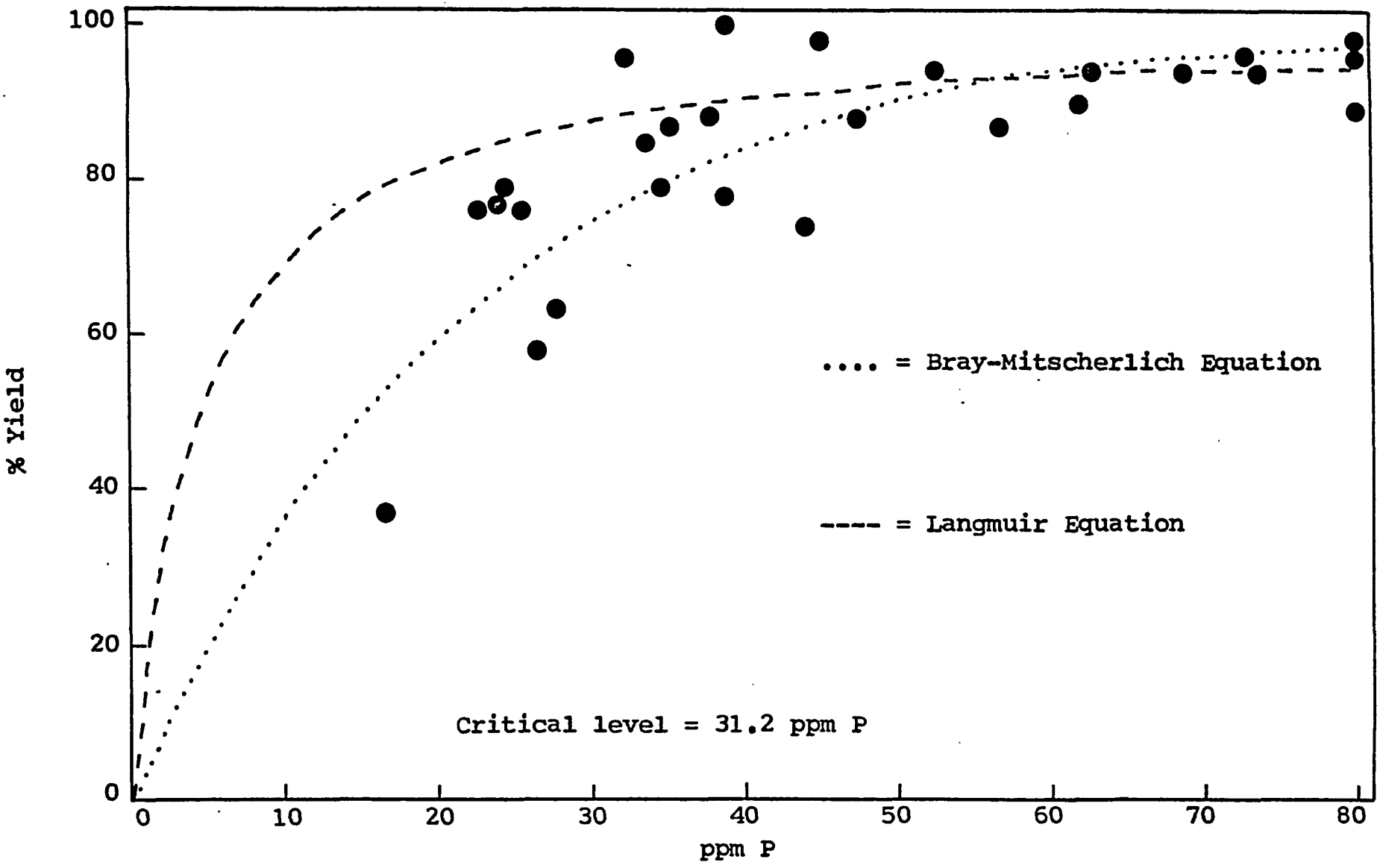

FIGURE 12. Relationship of % yield of rice to P extracted by natural reduction + Bray No.1.

Table 17

Effect of Natural Reduction + Bray No.2 on Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	53.0	940	1475	2172
Iberia c	1964	100.0	3800	3125	857
Crowley sil	1964	39.2	1620	575	2057
Bernard vfsl	1964	31.8	580	330	2057
Harris sil	1964	61.0	1660	1225	3429
Crowley sil	1964	12.4	1540	1475	2629
Midland sil	1964	74.2	1600	1000	389
Sharkey c	1964	544.5	7600	4000	217
Alligator sicl	1965	165.0	5400	575	400
Midland fsl	1965	35.5	550	1775	1486
Harris sil	1965	61.4	1160	900	1257
Crowley sil	1965	26.0	2140	1100	2629
Midland sil	1965	58.6	1340	1775	2400
Sharkey c	1965	503.3	7600	4000	217
Midland fsl	1966	38.6	400	800	1372
Crowley sil	1966	23.5	1440	330	2057
Patoutville sil	1966	74.2	2900	750	640
Crowley sil	1966	24.8	2200	900	2172
Midland sil	1966	50.5	1500	1475	2286
Midland fsl	1967	35.0	340	800	1257
Patoutville sil	1967	63.9	2600	350	720
Crowley sil	1971	24.8	2080	1100	2286
Crowley sil	1971	22.7	2080	1150	2515
Crowley sil	1972	42.3	1960	1175	2057
Crowley sil	1972	60.0	2080	1525	2115
Crowley sil	1973	23.7	2080	950	2057
Crowley sil	1973	24.4	2140	950	2172
Jeanerette sil	1974	109.3	1500	1500	160
Mean =		85.1	2244	1324	1645

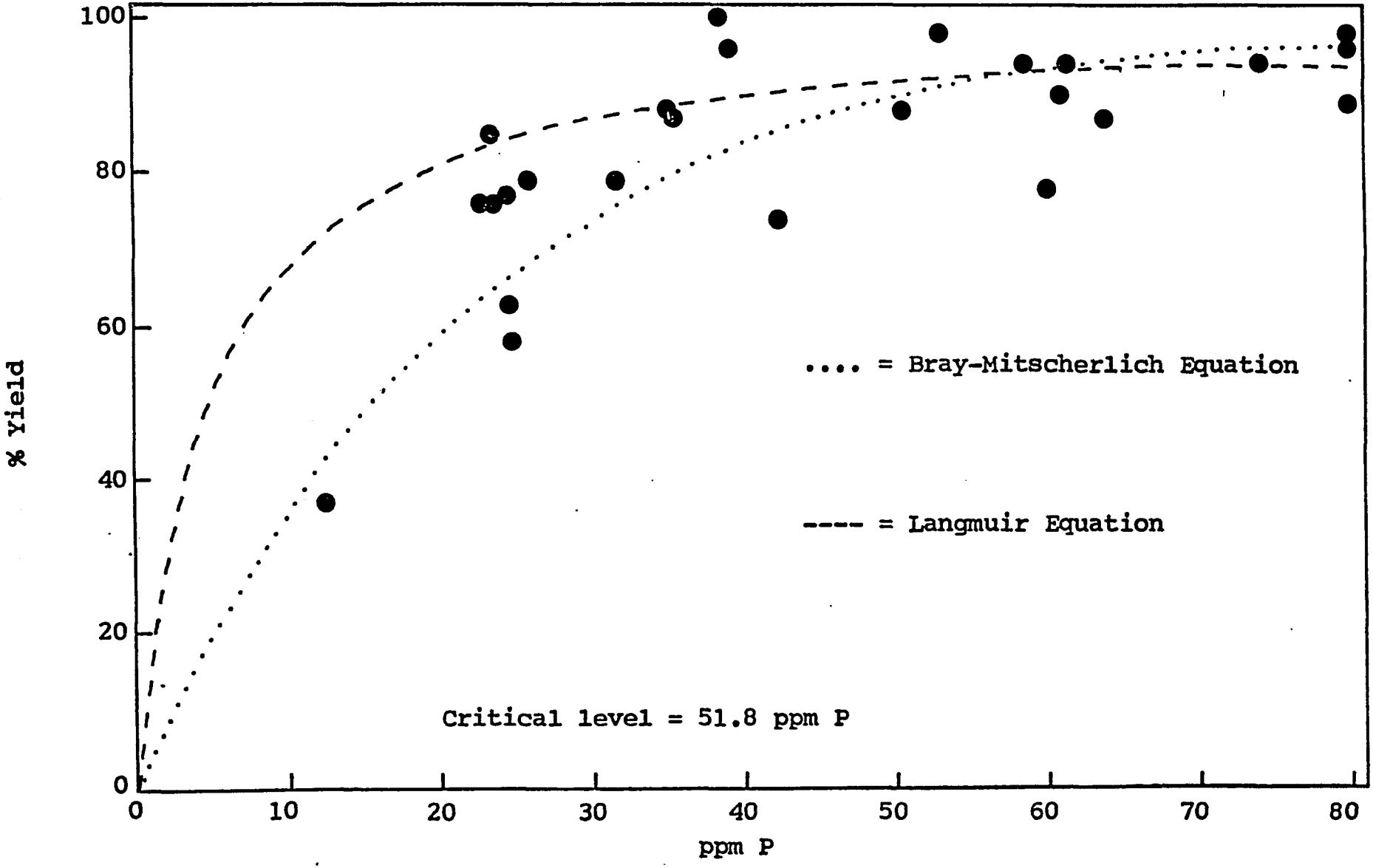

FIGURE 13. Relationship of % yield of rice to P extracted by natural reduction + Bray No. 2.

Table 18

Effect of Natural Reduction + 0.2N HCl on Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	44.4	2174	1538	578
Iberia c	1964	101.0	1505	5792	1942
Crowley sil	1964	27.1	2383	634	326
Bernard vfsl	1964	26.3	711	724	682
Harris sil	1964	44.0	2592	1720	892
Crowley sil	1964	8.9	3177	1629	630
Midland sil	1964	68.7	1672	2353	578
Sharkey c	1964	525.2	9865	6697	2625
Alligator sicl	1965	153.5	6145	2896	1155
Midland fsl	1965	34.7	543	1991	242
Harris sil	1965	52.1	1505	1810	578
Crowley sil	1965	14.5	4264	1810	578
Midland sil	1965	53.7	1672	2534	420
Sharkey c	1965	509.0	9781	7240	735
Midland fsl	1966	42.8	460	996	205
Crowley sil	1966	24.2	2759	814	430
Patoutville sil	1966	60.6	3846	2534	735
Crowley sil	1966	21.0	4096	1538	1208
Midland sil	1966	50.1	2257	1448	630
Midland fsl	1967	36.8	418	634	158
Patoutville sil	1967	40.4	3637	1538	735
Crowley sil	1971	15.4	3848	1176	682
Crowley sil	1971	12.5	3219	1629	368
Crowley sil	1972	35.1	3720	1810	368
Crowley sil	1972	30.7	3887	1720	472
Crowley sil	1973	18.2	3678	1538	462
Crowley sil	1973	17.0	3637	1086	525
Jeanerette sil	1974	125.2	2006	2534	593
Mean =		78.3	3195	2156	698

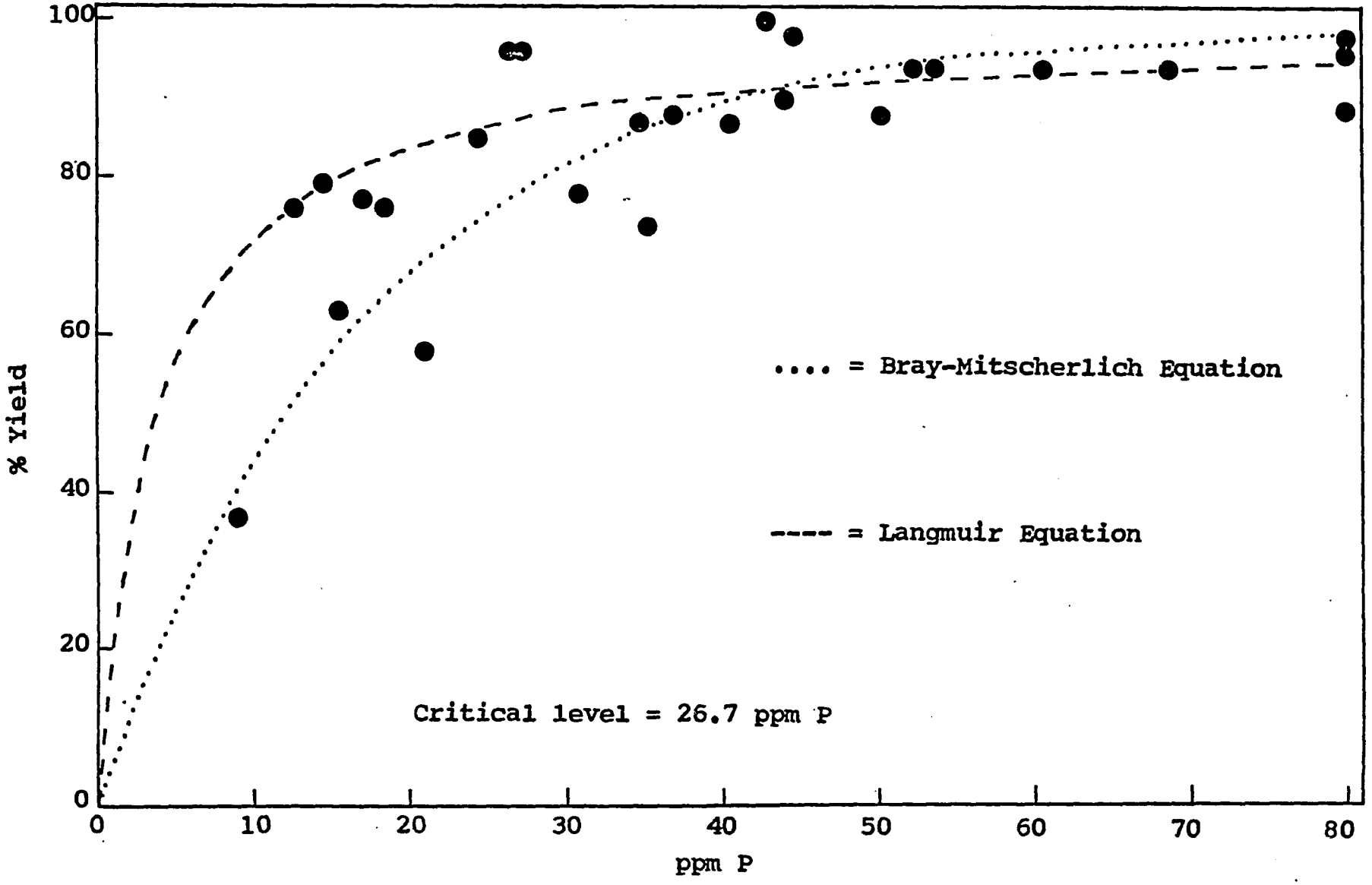

FIGURE 14. Relationship of % yield of rice to P extracted by natural reduction + 0.2N HCl.

No. 1 was third (R^2=0.5605**) and the naturally reduced + Bray No. 2 fourth (R^2=0.5127**) and finally the naturally reduced + Kapp's Texas Buffer having an R^2 value of 0.4647*. The regression equation of naturally reduced + 0.5M $NaHCO_3$ was:

$$\hat{Y} = 51.46 + 3.37X - 0.08X^2 + 0.0005X^3$$

(iii) Chemical Extraction in the Artificially Reduced Soils

There were no significant linear correlations between phosphorus and yield in the soils artificially reduced. When quadratic equation was used, only the artificially reduced + Bray No. 1 had a significant R^2 of 0.2955* and a regression equation of:

$$\hat{Y} = 72.39 + 0.40X - 0.001X^2$$

Even when the cubic equation was used, it did not increased the significance of the R^2 values of hte other extractants used. However, artificially reduced + Bray No. 1 had an R^2 value of 0.4113** and a regression equation of:

$$\hat{Y} = 63.69 + 0.92 - 0.007X^2 + 0.00001X^3$$

Judging from the overall discussion thus far, it was found that the Bray No. 1 showed a promising ability to correlate extractable phosphorus with rice yield. In both the air-dried soil and artificially reduced condition, Bray No. 1 had the highest R^2 value of the five chemical extractants used.

The highest R^2 values overall were obtained with by

Table 19

Effect of Artificial Reduction (0.1N $Na_2S_2O_4$) + 0.5M $NaHCO_3$ on Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	9.7	95	79	16
Iberia c	1964	7.5	60	49	5
Crowley sil	1964	6.3	104	324	32
Bernard vfsl	1964	10.1	104	138	47
Harris sil	1964	9.3	164	147	32
Crowley sil	1964	12.1	86	49	11
Midland sil	1964	22.4	86	59	11
Sharkey c	1964	29.9	52	39	5
Alligator sicl	1965	16.4	86	79	5
Midland fsl	1965	13.8	48	59	16
Harris sil	1965	13.4	104	98	47
Crowley sil	1965	11.2	82	69	5
Midland sil	1965	19.4	86	157	5
Sharkey c	1965	38.8	35	49	5
Midland fsl	1966	21.6	104	285	69
Crowley sil	1966	8.2	117	206	26
Patoutville sil	1966	9.7	95	49	5
Crowley sil	1966	6.3	99	88	5
Midland sil	1966	9.7	112	59	5
Midland fsl	1967	17.2	48	374	37
Patoutville sil	1967	8.6	99	79	11
Crowley sil	1971	6.7	95	88	11
Crowley sil	1971	6.3	91	98	11
Crowley sil	1972	7.8	112	59	5
Crowley sil	1972	9.3	91	79	5
Crowley sil	1973	8.2	95	88	5
Crowley sil	1973	6.3	99	88	5
Jeanerette sil	1974	56.7	65	88	5
Mean =		14.4	90	112	16

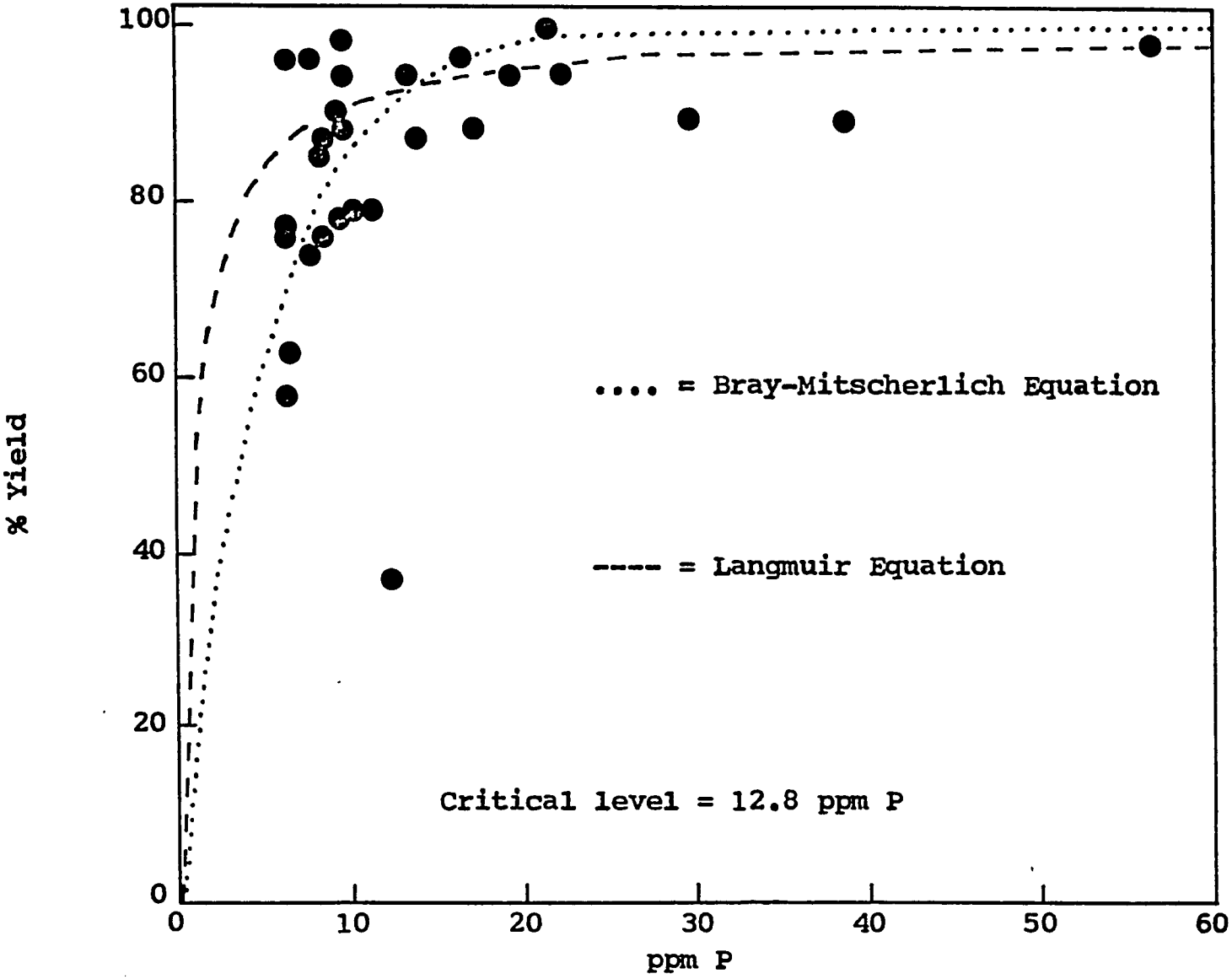

FIGURE 15. Relationship of % yield of rice to P extracted by artificial reduction + 0.5M $NaHCO_3$.

Table 20

Effect of Artificial Reduction (0.1N $Na_2S_2O_4$) + Kapp's Texas Buffer on Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	23.5	950	983	295
Iberia c	1964	25.4	2074	5505	343
Crowley sil	1964	18.3	1210	354	300
Bernard vfsl	1964	3.7	259	79	680
Harris sil	1964	7.1	950	875	543
Crowley sil	1964	11.5	1598	786	453
Midland sil	1964	44.0	562	1327	295
Sharkey c	1964	184.3	1901	7471	116
Alligator sicl	1965	45.5	1728	2949	142
Midland fsl	1965	11.2	173	895	84
Harris sil	1965	11.2	518	973	242
Crowley sil	1965	5.2	1382	1022	153
Midland sil	1965	25.4	475	1533	121
Sharkey c	1965	82.8	1210	7864	79
Midland fsl	1966	17.2	173	511	105
Crowley sil	1966	9.7	1210	206	195
Patoutville sil	1966	54.5	1858	1966	364
Crowley sil	1966	25.4	2246	609	327
Midland sil	1966	22.7	950	973	195
Midland fsl	1967	15.3	173	482	142
Patoutville sil	1967	39.6	2030	639	543
Crowley sil	1971	18.3	1901	649	364
Crowley sil	1971	13.8	1858	737	379
Crowley sil	1972	41.8	1987	659	321
Crowley sil	1972	13.4	994	1180	63
Crowley sil	1973	7.4	994	904	74
Crowley sil	1973	4.8	1037	904	79
Jeanerette sil	1974	79.8	432	3047	32
Mean =		30.8	1173	1646	251

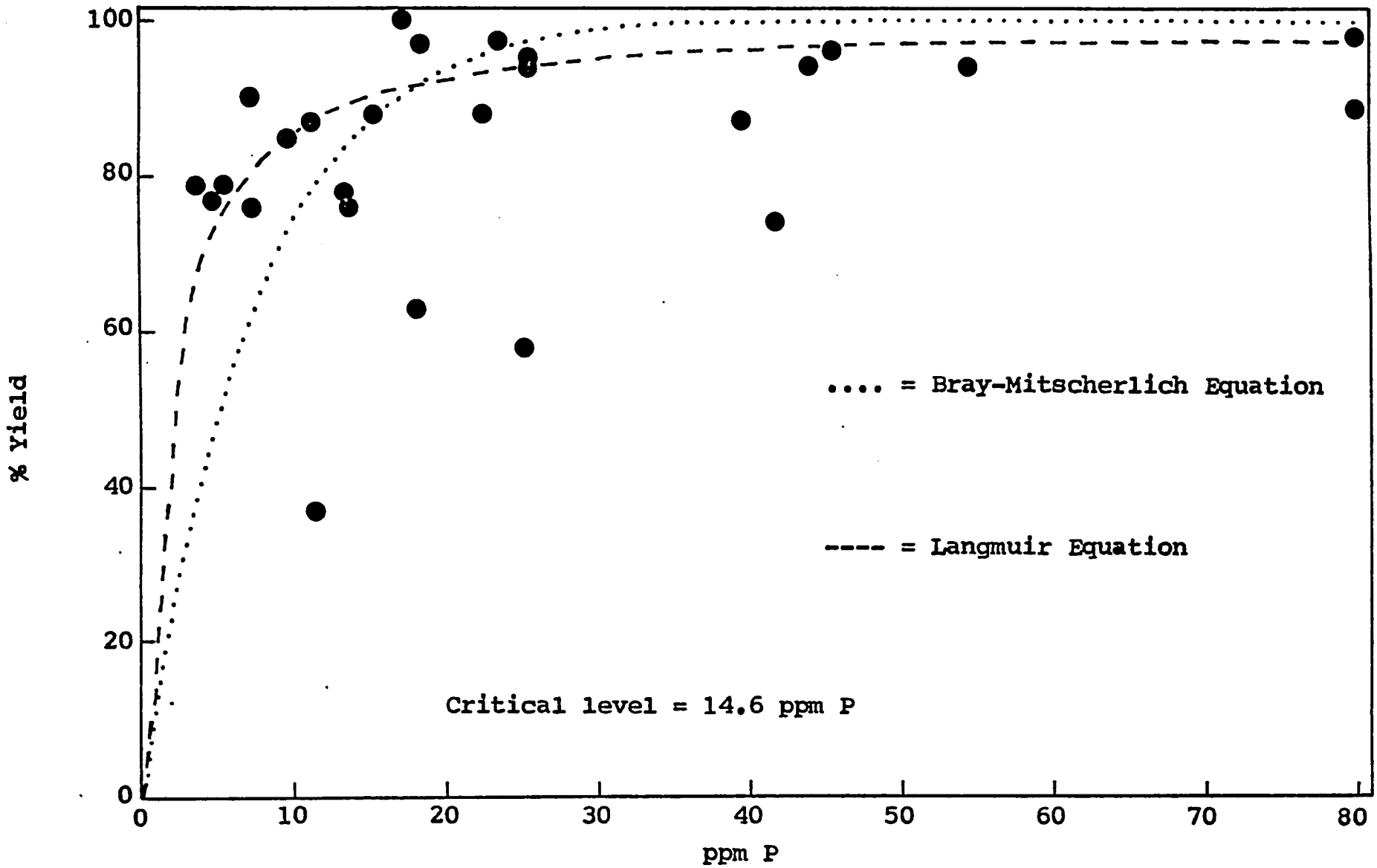

FIGURE 16. Relationship of % yield of rice to P extracted by artificial reduction + Kapp's Texas Buffer.

Table 21

Effect of Artificial Reduction (0.1N $Na_2S_2O_4$) + Bray No.1 on Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	32.6	2048	1125	1534
Iberia c	1964	67.0	3260	1438	2486
Crowley sil	1964	24.1	2592	562	1322
Bernard vfsl	1964	17.1	961	812	1693
Harris sil	1964	38.6	2174	938	2380
Crowley sil	1964	13.9	3010	1312	1693
Midland sil	1964	57.8	1672	1062	1322
Sharkey c	1964	284.8	4264	1875	1799
Alligator sicl	1965	127.0	4180	1000	2010
Midland fsl	1965	15.2	836	1438	899
Harris sil	1965	40.3	1463	1375	1957
Crowley sil	1965	21.9	2968	1062	1428
Midland sil	1965	34.9	1505	1062	1322
Sharkey c	1965	192.8	3344	2250	1587
Midland fsl	1966	20.2	1588	1125	952
Crowley sil	1966	18.5	2508	938	1428
Patoutville sil	1966	44.5	1547	1688	1587
Crowley sil	1966	14.8	1756	1375	1164
Midland sil	1966	22.0	1338	1188	1270
Midland fsl	1967	9.6	669	1000	794
Patoutville sil	1967	37.5	1463	1312	1957
Crowley sil	1971	14.1	1881	1688	1217
Crowley sil	1971	13.0	1672	1438	1322
Crowley sil	1972	22.0	1714	1750	1058
Crowley sil	1972	20.2	1254	1250	1164
Crowley sil	1973	10.4	1087	1438	1322
Crowley sil	1973	8.2	1087	1312	1217
Jeanerette sil	1974	83.1	1254	2188	1164
Mean =		46.6	1968	1321	1466

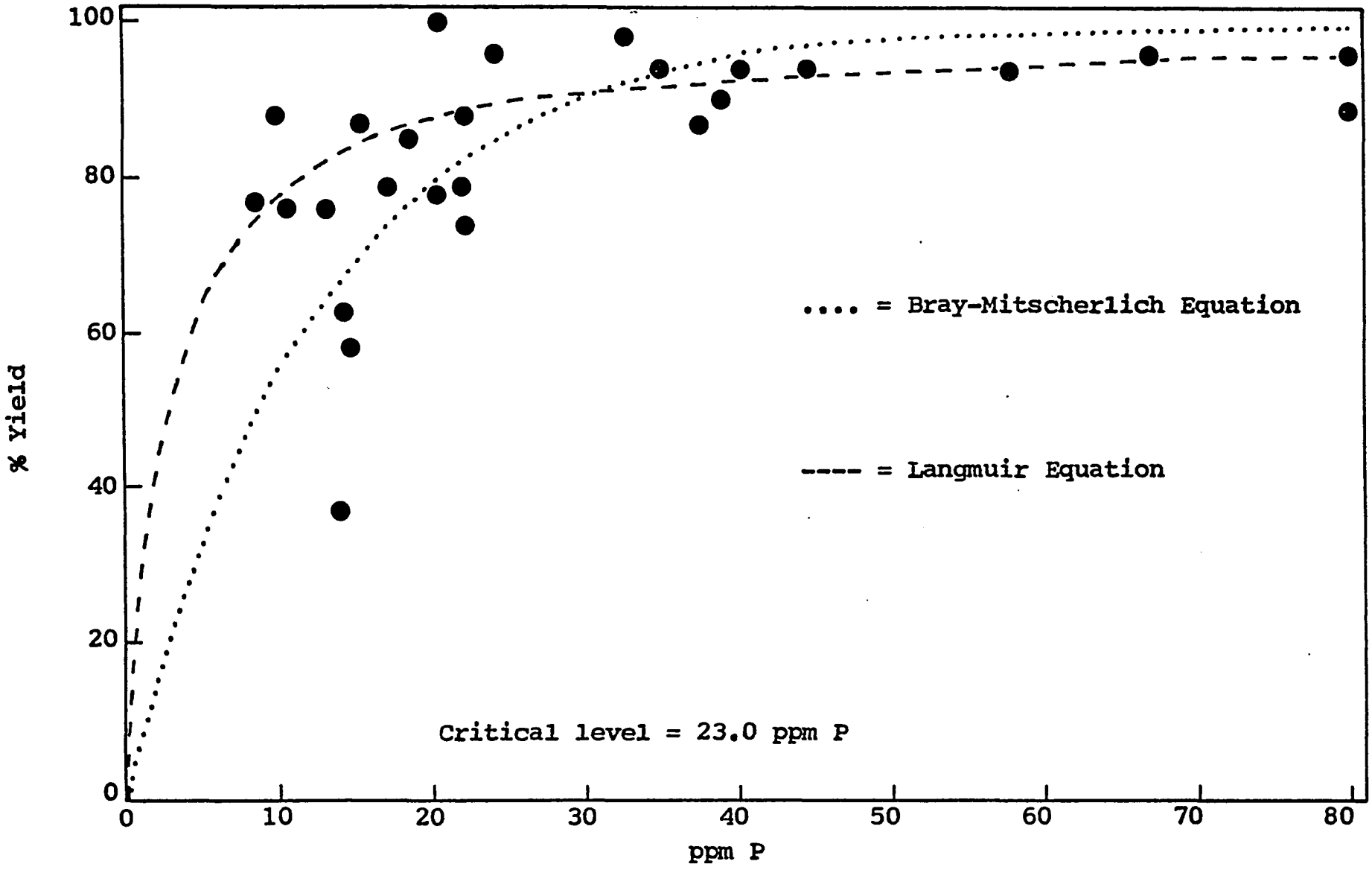

FIGURE 17. Relationship of % yield of rice to P extracted by artificial reduction + Bray No.1.

Table 22

Effect of Artificial Reduction (0.1N $Na_2S_2O_4$) + Bray No.2 on Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	35.3	2985	128	3689
Iberia c	1964	95.0	6396	550	4901
Crowley sil	1964	25.4	3624	49	2108
Bernard vfsl	1964	18.7	757	20	2055
Harris sil	1964	41.9	3091	108	3215
Crowley sil	1964	16.5	4795	98	3531
Midland sil	1964	62.1	1919	177	2055
Sharkey c	1964	464.5	9168	875	4427
Alligator sicl	1965	155.6	6609	216	4532
Midland fsl	1965	16.8	437	157	3162
Harris sil	1965	44.3	1599	108	2477
Crowley sil	1965	32.2	4264	88	2319
Midland sil	1965	37.4	1492	197	5586
Sharkey c	1965	403.9	6183	1150	3794
Midland fsl	1966	21.5	341	69	1476
Crowley sil	1966	22.4	3411	29	2213
Patoutville sil	1966	105.9	4797	177	3320
Crowley sil	1966	35.5	5330	79	3267
Midland sil	1966	34.1	2452	138	2213
Midland fsl	1967	19.8	309	79	1634
Patoutville sil	1967	86.2	4904	49	3742
Crowley sil	1971	32.2	5223	88	2582
Crowley sil	1971	31.0	4690	98	3215
Crowley sil	1972	52.7	5437	98	3373
Crowley sil	1972	41.9	4371	138	3531
Crowley sil	1973	28.0	4477	108	3742
Crowley sil	1973	22.4	4371	98	2213
Jeanerette sil	1974	107.7	2132	452	2530
Mean =		74.7	3770	201	3104

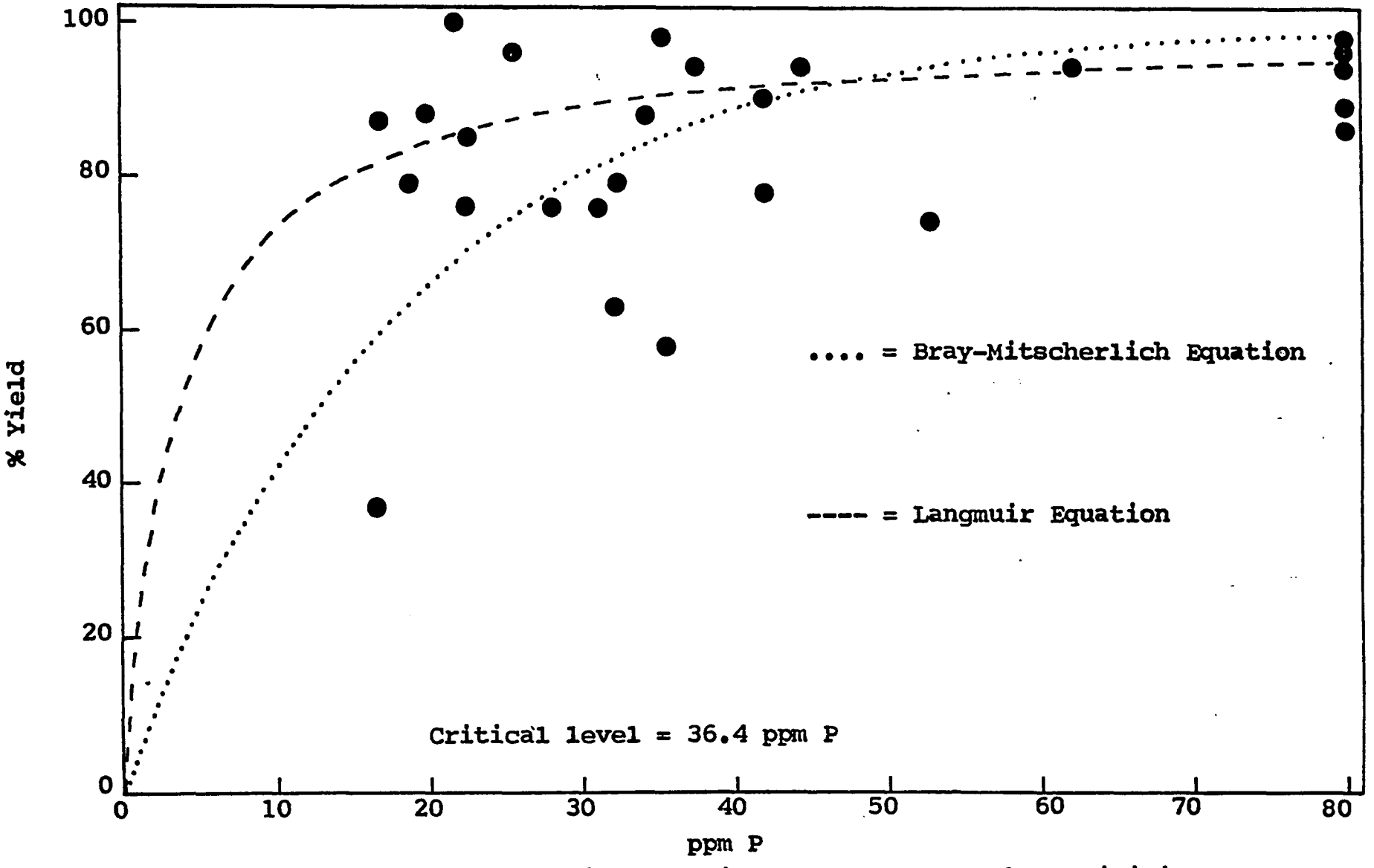

FIGURE 18. Relationship of % yield of rice to P extracted by artificial reduction + Bray No.2.

Table 23

Effect of Artificial Reduction (0.1N $Na_2S_2O_4$) + 0.2N HCl on Extractable Phosphorus, Iron, Calcium, and Aluminum in Soils - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	32.8	2239	659	437
Iberia c	1964	105.2	5543	2949	1370
Crowley sil	1964	23.9	3091	236	843
Bernard vfsl	1964	16.8	629	10	949
Harris sil	1964	34.6	2665	492	1159
Crowley sil	1964	14.9	3731	501	738
Midland sil	1964	56.0	1279	865	448
Sharkey c	1964	519.5	7675	2064	1265
Alligator sicl	1965	134.4	4264	1140	843
Midland fsl	1965	13.4	320	688	264
Harris sil	1965	41.1	1279	501	790
Crowley sil	1965	24.3	2878	492	474
Midland sil	1965	33.6	1066	944	353
Sharkey c	1965	463.5	5756	2163	1159
Midland fsl	1966	21.5	284	315	227
Crowley sil	1966	17.9	2132	69	379
Patoutville sil	1966	97.0	4371	796	790
Crowley sil	1966	35.8	5330	315	632
Midland sil	1966	32.2	2025	708	474
Midland fsl	1967	17.2	309	295	221
Patoutville sil	1967	79.1	4477	324	1001
Crowley sil	1971	31.0	4477	383	685
Crowley sil	1971	28.0	4051	482	685
Crowley sil	1972	51.4	4904	403	580
Crowley sil	1972	27.5	2558	678	321
Crowley sil	1973	18.7	2452	501	311
Crowley sil	1973	15.3	2345	492	316
Jeanerette sil	1974	98.5	1215	1661	1159
Mean =		74.5	2977	754	674

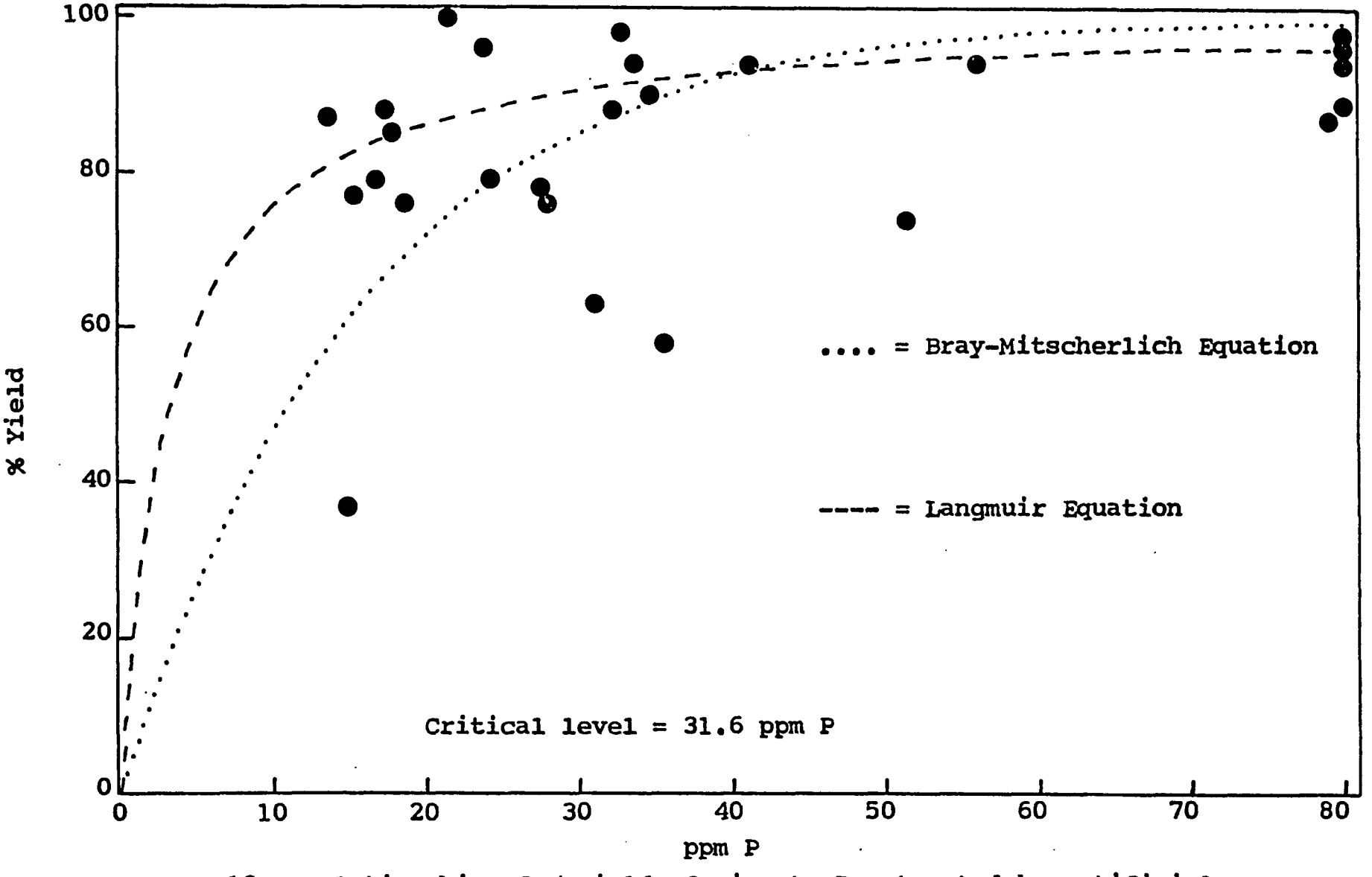

FIGURE 19. Relationship of % yield of rice to P extracted by artificial reduction + 0.2N HCl.

Table 24

Relationship of Percent Yield of Rice and Phosphorus Extracted with Chemical Extractants Under Air-Dried, Naturally Reduced, and Artificially Reduced Conditions, Using Linear, Quadratic, and Cubic Equations.

Extraction Procedure	Linear Equation	Quadratic Equation	Cubic Equation
5) 0.5M $NaHCO_3$	$r^2 = 0.1317$ $\hat{Y} = 78.29 + 0.67X$	$R^2 = 0.3699^{**}$ $\hat{Y} = 63.98 + 3.92X - 0.101X^2$	$R^2 = 0.3996^{**}$ $\hat{Y} = 56.60 + 6.71X - 0.35X^3 + 0.005X^3$
6) Kapp's Texas Buffer	$r^2 = 0.1386$ $\hat{Y} = 79.60 + 0.58X$	$R^2 = 0.4818^{**}$ $\hat{Y} = 65.70 + 4.83X - 0.129X^2$	$R^2 = 0.5486^{**}$ $\hat{Y} = 59.00 + 8.19X - 0.47X^2 + 0.008X^3$
7) Bray No.1	$r^2 = 0.2093^{*}$ $\hat{Y} = 77.74 + 0.33X$	$R^2 = 0.5549^{**}$ $\hat{Y} = 63.67 + 1.97X - 0.023X^2$	$R^2 = 0.6401^{**}$ $\hat{Y} = 54.89 + 4.04X - 0.12X^2 + 0.001X^3$
8) Bray No.2	$r^2 = 0.0939$ $\hat{Y} = 80.88 + 0.07X$	$R^2 = 0.4219^{**}$ $\hat{Y} = 70.87 + 0.64X - 0.002X^2$	$R^2 = 0.5268^{**}$ $\hat{Y} = 64.48 + 1.23X - 0.01X^2 + 0.00003X^3$

Table 24 (continued)

Extraction Procedure	Linear Equation	Quadratic Equation	Cubic Equation
9) 0.2N HCl	$r^2 = 0.0662$ $\hat{Y} = 81.87 + 0.06X$	$R^2 = 0.3512^{**}$ $\hat{Y} = 75.23 + 0.62X - 0.002X^2$	$R^2 = 0.4524^{**}$ $\hat{Y} = 71.39 + 1.17X - 0.01X^2 + 0.00003X^3$
10) Naturally Reduced + 0.5M $NaHCO_3$	$r^2 = 0.2041^{**}$ $\hat{Y} = 77.30 + 0.29X$	$R^2 = 0.5390^{**}$ $\hat{Y} = 60.16 + 1.93X - 0.02X^2$	$R^2 = 0.5975^{**}$ $\hat{Y} = 51.46 + 3.37X - 0.08X^2 + 0.0005X^3$
11) Naturally Reduced + Kapp's Texas Buffer	$r^2 = 0.0858$ $\hat{Y} = 80.87 + 0.06X$	$R^2 = 0.3581^{**}$ $\hat{Y} = 70.75 + 0.50X - 0.002X^2$	$R^2 = 0.4647^{**}$ $\hat{Y} = 62.62 + 1.04X - 0.008X^2 + 0.00002X^3$
12) Naturally Reduced + Bray No. 1	$r^2 = 0.1126$ $\hat{Y} = 79.41 + 0.06X$	$R^2 = 0.4317^{**}$ $\hat{Y} = 62.93 + 0.51X - 0.001X^2$	$R^2 = 0.5605^{**}$ $\hat{Y} = 47.12 + 1.15X - 0.007X^2 + 0.00001X^3$
13) Naturally Reduced + Bray No. 2	$r^2 = 0.0632$ $\hat{Y} = 81.40 + 0.027X$	$R^2 = 0.4189^{**}$ $\hat{Y} = 66.89 + 0.36X - 0.0006X^2$	$R^2 = 0.5127^{**}$ $\hat{Y} = 59.10 + 0.65X - 0.003X^2 + 0.000003X^3$
14) Naturally Reduced + 0.2N HCl	$r^2 = 0.0647$ $\hat{Y} = 81.58 + 0.027X$	$R^2 = 0.4162^{**}$ $\hat{Y} = 69.74 + 0.35X - 0.0006X^2$	$R^2 = 0.5634^{**}$ $\hat{Y} = 58.45 + 0.88X - 0.005X^2 + 0.00001X^3$

Table 24 (continued)

Extraction Procedure	Linear Equation	Quadratic Equation	Cubic Equation
15) Artificially Reduced + 0.5M $NaHCO_3$	$r^2 = 0.1071$ $\hat{Y} = 78.12 + 0.40X$	$R^2 = 0.1238$ $\hat{Y} = 73.37 + 0.97X - 0.01X^2$	$R^2 = 0.1417$ $\hat{Y} = 63.43 + 2.71X - 0.09X^2 + 0.0009X^3$
16) Artificially Reduced + Kapp's Texas Buffer	$r^2 = 0.0639$ $\hat{Y} = 80.77 + 0.09X$	$R^2 = 0.1275$ $\hat{Y} = 76.31 + 0.35X - 0.002X^2$	$R^2 = 0.1278$ $\hat{Y} = 75.76 + 0.41X - 0.003X^2 + 0.000004X^3$
17) Artificially Reduced + Bray No.1	$r^2 = 0.0969$ $\hat{Y} = 80.43 + 0.069X$	$R^2 = 0.2955*$ $\hat{Y} = 72.39 + 0.40X - 0.001X^2$	$R^2 = 0.4113**$ $\hat{Y} = 63.69 + 0.92X - 0.007X^2 + 0.00001X^3$
18) Artificially Reduced + Bray No.2	$r^2 = 0.0546$ $\hat{Y} = 81.44 + 0.03X$	$R^2 = 0.2027$ $\hat{Y} = 73.20 + 0.24X - 0.0005X^2$	$R^2 = 0.2230$ $\hat{Y} = 69.77 + 0.38X - 0.002X^2 + 0.000002X^3$
19) Artificially Reduced + 0.2N HCl	$r^2 = 0.0446$ $\hat{Y} = 81.92 + 0.02X$	$R^2 = 0.1938$ $\hat{Y} = 74.38 + 0.23X - 0.0004X^2$	$R^2 = 0.2078$ $\hat{Y} = 72.28 + 0.33X - 0.001X^2 + 0.000001X^3$

Bray No. 1 using the air-dried soils.

When the soils were naturally reduced prior to chemical extraction, the 0.5M $NaHCO_3$ had a much higher R^2 value in both the quadratic and cubic equations. The Bray No. 1 Extractant was third when cubic equation was used.

Relationship of Labile Phosphorus Under Naturally Oxidized, Naturally Reduced, and Artificially Reduced Conditions with Percent Yield of Rice.

The counting efficiency and the color quenching were taken into consideration so that the disintegration rate of ^{32}P can be determined as accurately as possible. The counting efficiency was found to range from 11.63% to 26.58% while the color quenching ranged from zero to as high as 50%.

Tables 25 to 32 show the amount of labile phosphorus under naturally oxidized, naturally and artificially reduced soil conditions. It can be seen in Table 33 that there were no significant coefficient of determinations (R^2) in all the conditions mentioned above irrespective of using linear, quadratic or cubic equations.

Table 25

Concentration of Labile Phosphorus, Iron, Calcium, and Aluminum in Oxidized Condition of Soils Using 0.34 uCi of ^{32}P per sample - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	25.9	135	11	16
Iberia c	1964	63.0	135	8	33
Crowley sil	1964	24.3	390	3	32
Bernard vfsl	1964	12.1	65	15	46
Harris sil	1964	34.4	405	23	14
Crowley sil	1964	27.9	70	6	251
Midland sil	1964	42.7	80	8	27
Sharkey c	1964	148.5	105	97	229
Alligator sicl	1965	39.7	125	7	223
Midland fsl	1965	15.1	70	15	60
Harris sil	1965	28.7	165	17	57
Crowley sil	1965	17.7	60	7	19
Midland sil	1965	31.9	90	10	19
Sharkey c	1965	168.4	60	118	114
Midland fsl	1966	11.7	80	11	13
Crowley sil	1966	14.6	175	7	206
Patoutville sil	1966	37.3	120	11	22
Crowley sil	1966	4.8	90	3	149
Midland sil	1966	19.1	150	6	34
Midland fsl	1967	7.8	45	15	63
Patoutville sil	1967	35.0	80	6	106
Crowley sil	1971	23.1	105	2	32
Crowley sil	1971	9.3	65	19	137
Crowley sil	1972	25.6	110	8	16
Crowley sil	1972	35.5	115	3	97
Crowley sil	1973	16.8	80	1	74
Crowley sil	1973	21.5	70	3	117
Jeanerette sil	1974	29.6	90	24	229
Mean =		34.7	119	17	87

Table 26

Concentration of Labile Phosphorus, Iron, Calcium, and Aluminum in Oxidized Condition of Soils Using 0.60 uCi of ^{32}P per sample - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	38.3	130	21	11
Iberia c	1964	42.0	70	30	57
Crowley sil	1964	19.8	135	22	11
Bernard vfsl	1964	15.9	165	30	34
Harris sil	1964	23.9	225	48	11
Crowley sil	1964	34.3	180	7	451
Midland sil	1964	36.0	55	24	23
Sharkey c	1964	294.5	80	141	114
Alligator sicl	1965	56.4	205	9	400
Midland fsl	1965	9.1	90	18	46
Harris sil	1965	26.8	140	54	17
Crowley sil	1965	3.5	45	66	17
Midland sil	1965	26.4	25	46	11
Sharkey c	1965	164.8	40	138	34
Midland fsl	1966	12.9	55	22	11
Crowley sil	1966	16.8	320	9	189
Patoutville sil	1966	9.4	25	181	17
Crowley sil	1966	10.5	145	9	69
Midland sil	1966	20.7	90	11	46
Midland fsl	1967	8.8	45	27	17
Patoutville sil	1967	23.0	70	14	69
Crowley sil	1971	8.1	55	14	69
Crowley sil	1971	8.9	50	18	34
Crowley sil	1972	11.8	85	14	11
Crowley sil	1972	19.7	140	14	80
Crowley sil	1973	7.7	75	11	69
Crowley sil	1973	14.3	105	14	91
Jeanerette sil	1974	63.1	160	30	320
Mean =		36.7	107	37	83

Table 27

Concentration of Labile Phosphorus, Iron, Calcium, and Aluminum in Natural Reduction Condition of Soils Using 0.34 uCi of ^{32}P per sample - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	22.9	335	40	194
Iberia c	1964	51.5	120	201	69
Crowley sil	1964	33.4	340	34	171
Bernard vfsl	1964	31.1	255	53	46
Harris sil	1964	18.5	130	18	194
Crowley sil	1964	94.1	115	165	34
Midland sil	1964	23.5	120	31	206
Sharkey c	1964	185.9	70	490	11
Alligator sicl	1965	97.9	185	85	34
Midland fsl	1965	1.2	125	66	149
Harris sil	1965	17.4	80	25	91
Crowley sil	1965	126.3	140	112	57
Midland sil	1965	38.4	130	41	183
Sharkey c	1965	207.1	70	550	11
Midland fsl	1966	2.5	30	14	126
Crowley sil	1966	31.8	380	21	217
Patoutville sil	1966	56.9	145	340	57
Crowley sil	1966	62.7	185	85	46
Midland sil	1966	23.1	160	41	171
Midland fsl	1967	1.3	100	48	103
Patoutville sil	1967	113.7	175	81	103
Crowley sil	1971	52.7	155	103	63
Crowley sil	1971	92.6	160	153	34
Crowley sil	1972	38.8	220	99	80
Crowley sil	1972	32.0	195	121	57
Crowley sil	1973	58.6	120	78	46
Crowley sil	1973	36.8	195	88	63
Jeanerette sil	1974	19.1	75	75	80
Mean =		56.1	161	116	96

Table 28

Concentration of Labile Phosphorus, Iron, Calcium, and Aluminum in Natural Reduction Condition of Soils Using 0.60 uCi of ^{32}P per sample - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	24.1	180	68	160
Iberia c	1964	48.3	130	420	40
Crowley sil	1964	36.5	400	80	183
Bernard vfsl	1964	34.5	225	140	23
Harris sil	1964	18.9	120	80	103
Crowley sil	1964	92.0	190	310	46
Midland sil	1964	36.0	110	40	160
Sharkey c	1964	251.1	125	730	11
Alligator sicl	1965	105.9	245	210	23
Midland fsl	1965	5.6	100	140	69
Harris sil	1965	24.9	80	80	29
Crowley sil	1965	106.9	180	310	11
Midland sil	1965	28.2	125	60	149
Sharkey c	1965	241.8	95	610	11
Midland fsl	1966	6.3	110	80	69
Crowley sil	1966	33.0	355	60	120
Patoutville sil	1966	57.7	115	570	23
Crowley sil	1966	56.0	235	230	23
Midland sil	1966	29.6	190	100	63
Midland fsl	1967	12.2	95	160	23
Patoutville sil	1967	78.7	150	230	46
Crowley sil	1971	55.8	195	250	29
Crowley sil	1971	76.4	140	290	23
Crowley sil	1972	36.7	240	250	11
Crowley sil	1972	41.3	185	270	23
Crowley sil	1973	55.4	145	230	6
Crowley sil	1973	56.6	160	200	29
Jeanerette sil	1974	47.4	75	200	17
Mean =		60.6	168	228	54

Table 29

Concentration of Labile Phosphorus, Iron, Calcium, and Aluminum in Artificial Reduction Condition (0.1N $Na_2S_2O_4$) of Soils Using 0.34 uCi of ^{32}P per sample - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	1.3	1300	1240	146
Iberia c	1964	22.0	2150	4560	106
Crowley sil	1964	0.7	1800	400	191
Bernard vfsl	1964	4.7	550	40	426
Harris sil	1964	6.9	1650	1180	325
Crowley sil	1964	2.4	1950	1040	179
Midland sil	1964	2.4	950	1360	135
Sharkey c	1964	105.5	2150	6160	84
Alligator sicl	1965	32.3	3200	2000	179
Midland fsl	1965	0.5	350	1100	90
Harris sil	1965	4.3	950	1040	224
Crowley sil	1965	4.3	2550	740	179
Midland sil	1965	1.5	900	1360	135
Sharkey c	1965	116.2	2250	5920	78
Midland fsl	1966	1.0	300	500	101
Crowley sil	1966	1.2	2050	40	269
Patoutville sil	1966	16.2	2100	1280	168
Crowley sil	1966	2.5	2250	640	135
Midland sil	1966	1.2	1450	1260	135
Midland fsl	1967	0.9	250	520	95
Patoutville sil	1967	19.3	2100	840	258
Crowley sil	1971	2.7	2100	840	140
Crowley sil	1971	3.4	1950	780	168
Crowley sil	1972	2.2	2100	920	123
Crowley sil	1972	4.1	2150	1080	123
Crowley sil	1973	3.3	2150	760	135
Crowley sil	1973	2.2	2050	680	146
Jeanerette sil	1974	5.0	900	2240	101
Mean =		13.2	1664	1447	163

Table 30

Concentration of Labile Phosphorus, Iron, Calcium, and Aluminum in Artificial Reduction Condition (0.1N $Na_2S_2O_4$) of Soils Using 0.60 uCi of ^{32}P per sample - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	4.6	1800	1160	168
Iberia c	1964	21.0	3250	4160	106
Crowley sil	1964	5.2	2600	320	247
Bernard vfsl	1964	5.5	750	60	493
Harris sil	1964	11.2	1900	960	370
Crowley sil	1964	5.3	3100	800	224
Midland sil	1964	6.6	1350	1160	168
Sharkey c	1964	189.0	4050	5040	78
Alligator sicl	1965	47.6	4350	1680	235
Midland fsl	1965	0.6	500	1040	123
Harris sil	1965	9.8	1300	1160	247
Crowley sil	1965	12.8	3800	620	213
Midland sil	1965	4.2	1250	1120	157
Sharkey c	1965	187.4	3900	5040	78
Midland fsl	1966	2.3	400	430	126
Crowley sil	1966	5.6	2650	100	336
Patoutville sil	1966	35.5	3250	1220	235
Crowley sil	1966	8.3	3550	500	179
Midland sil	1966	4.8	1850	980	219
Midland fsl	1967	1.4	350	480	123
Patoutville sil	1967	37.6	3800	460	426
Crowley sil	1971	12.1	3800	640	247
Crowley sil	1971	9.1	2950	670	247
Crowley sil	1972	12.4	3550	620	179
Crowley sil	1972	7.1	3250	660	247
Crowley sil	1973	8.6	3450	500	219
Crowley sil	1973	6.9	3450	520	224
Jeanerette sil	1974	12.3	1500	1840	146
Mean =		24.1	2560	1212	216

Table 31

Concentration of Labile Phosphorus, Iron, Calcium, and Aluminum in Artificial Reduction Condition (0.2N $Na_2S_2O_4$) of Soils Using 0.34 uCi of ^{32}P per sample - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	1.5	2050	1020	269
Iberia c	1964	37.5	4150	4800	126
Crowley sil	1964	0.9	3000	280	336
Bernard vfsl	1964	1.6	800	50	650
Harris sil	1964	7.0	2000	940	471
Crowley sil	1964	5.2	3800	660	359
Midland sil	1964	2.5	1400	1160	224
Sharkey c	1964	72.9	5200	5960	56
Alligator sicl	1965	55.5	4950	1840	207
Midland fsl	1965	0.8	500	880	168
Harris sil	1965	6.6	1350	760	381
Crowley sil	1965	14.0	4650	620	280
Midland sil	1965	1.6	1300	1160	247
Sharkey c	1965	82.2	5050	6280	67
Midland fsl	1966	0.8	450	360	191
Crowley sil	1966	1.7	3050	60	404
Patoutville sil	1966	29.6	3900	1200	258
Crowley sil	1966	3.5	4050	470	247
Midland sil	1966	1.3	1850	920	303
Midland fsl	1967	0.8	350	380	157
Patoutville sil	1967	22.9	3800	560	426
Crowley sil	1971	3.5	3700	620	247
Crowley sil	1971	3.7	3400	720	291
Crowley sil	1972	1.8	3400	740	191
Crowley sil	1972	1.8	3350	760	258
Crowley sil	1973	1.1	3800	500	252
Crowley sil	1973	1.1	3250	540	258
Jeanerette sil	1974	4.9	1450	2240	168
Mean =		13.2	2857	1303	268

Table 32

Concentration of Labile Phosphorus, Iron, Calcium, and Aluminum in Artificial Reduction Condition (0.2N $Na_2S_2O_4$) of Soils Using 0.60 uCi of ^{32}P per sample - ppm

Soil Series	Year	P	Fe	Ca	Al
Midland sil	1963	1.7	2250	1300	123
Iberia c	1964	48.6	5650	4800	45
Crowley sil	1964	7.7	3550	440	135
Bernard vfsl	1964	5.9	1050	60	493
Harris sil	1964	13.3	2350	1260	213
Crowley sil	1964	24.1	5550	1300	78
Midland sil	1964	14.0	2350	1360	135
Sharkey c	1964	139.7	6050	4880	34
Alligator sicl	1965	64.1	5400	2320	78
Midland fsl	1965	1.7	750	1040	101
Harris sil	1965	12.8	1600	1090	207
Crowley sil	1965	55.4	7350	1050	45
Midland sil	1965	7.1	1450	1120	247
Sharkey c	1965	177.2	6200	4880	22
Midland fsl	1966	1.4	550	450	135
Crowley sil	1966	7.0	3800	100	303
Patoutville sil	1966	50.4	5300	1600	101
Crowley sil	1966	15.9	5650	700	90
Midland sil	1966	7.2	2250	1220	151
Midland fsl	1967	2.4	500	440	101
Patoutville sil	1967	65.3	5800	820	213
Crowley sil	1971	13.9	5150	840	135
Crowley sil	1971	14.5	4800	920	163
Crowley sil	1972	19.1	4800	720	168
Crowley sil	1972	11.4	5050	840	185
Crowley sil	1973	11.9	5150	600	179
Crowley sil	1973	8.8	4900	560	202
Jeanerette sil	1974	16.9	2050	2160	157
Mean =		29.3	3832	1388	151

Table 33

The Coefficient of Determinations (r^2 and R^2) of Labile Phosphorus Determined by Two Different Concentrations of ^{32}P Under Naturally Oxidized, Naturally Reduced, and Artificially Reduced Conditions with Percent Yield of Rice, Using Linear, Quadratic, and Cubic Equations.

Extraction Procedure	r^2 Linear Equation	R^2 Quadratic Equation	R^2 Cubic Equation
20(i) Natural Oxidation Using 0.34 uCi ^{32}P	0.0495	0.1529	0.1565
(ii) Natural Oxidation Using 0.60 uCi ^{32}P	0.0345	0.1013	0.1425
21(i) Natural Reduction Using 0.34 uCi ^{32}P	0.0254	0.1927	0.1937
(ii) Natural Reduction Using 0.60 uCi ^{32}P	0.0064	0.1680	0.1736
22(i) Artificial Reduction (0.1N $Na_2S_2O_4$) Using 0.34 uCi ^{32}P	0.0305	0.0881	0.0885
(ii) Artificial Reduction (0.1N $Na_2S_2O_4$) Using 0.60 uCi ^{32}P	0.0234	0.0612	0.0821
23(i) Artificial Reduction (0.2N $Na_2S_2O_4$) Using 0.34 uCi ^{32}P	0.0579	0.0776	0.0993
(ii) Artificial Reduction (0.2N $Na_2S_2O_4$) Using 0.60 uCi ^{32}P	0.0166	0.0288	0.0758

Relationship Between the Labile Phosphorus in the Naturally Oxidized, Naturally Reduced, and Artificially Reduced Soils.

The coefficient of determinations between the labile phosphorus and the percent yield of rice were not that impressive (Table 33). On the other hand there were highly significant linear relationship for the labile phosphorus between the naturally oxidized, naturally reduced, and artificially reduced conditions (Tables 34 and 35).

Table 34

Simple Correlation Coefficient (r) for the Relationships of Labile Phosphorus in the Naturally Oxidized, Naturally Reduced, and Artificially Reduced Conditions, Using 0.34 uCi of ^{32}P.

	Naturally Reduced	Artificially Reduced (0.1N $Na_2S_2O_4$)	Artificially Reduced (0.2N $Na_2S_2O_4$)
Naturally Oxidized	0.7502**	0.9643**	0.8864**
Naturally Reduced	-	0.8223**	0.8144**
Artificially Reduced (0.1N $Na_2S_2O_4$)	-	-	0.9344**

Using 0.34 uCi of ^{32}P in the experiment, the highest correlation was observed between artificially reduced (0.1N $Na_2S_2O_4$) against naturally oxidized conditions (r = 0.9643**). When labile P in naturally reduced was correlated against labile P in artificially reduced conditions, the correlation coefficients of 0.8223** and 0.8144 were found in the 0.1N and 0.2N $Na_2S_2O_4$ respectively.

Table 35

Simple Correlation Coefficient (r) for the Relationships of Labile Phosphorus in the Naturally Oxidized, Naturally Reduced, and Artificially Reduced Conditions, Using 0.60 uCi of ^{32}P.

	Naturally Reduced	Artificially Reduced (0.1N $Na_2S_2O_4$)	Artificially Reduced (0.2N $Na_2S_2O_4$)
Naturally Oxidized	0.8443**	0.9166**	0.8024**
Naturally Reduced	-	0.9302**	0.9383**
Artificially Reduced (0.1N $Na_2S_2O_4$)	-	-	0.9511**

A different pattern was established when 0.60 uCi of ^{32}P was used. The highest r was observed between the two different concentrations of $Na_2S_2O_4$ used. The naturally

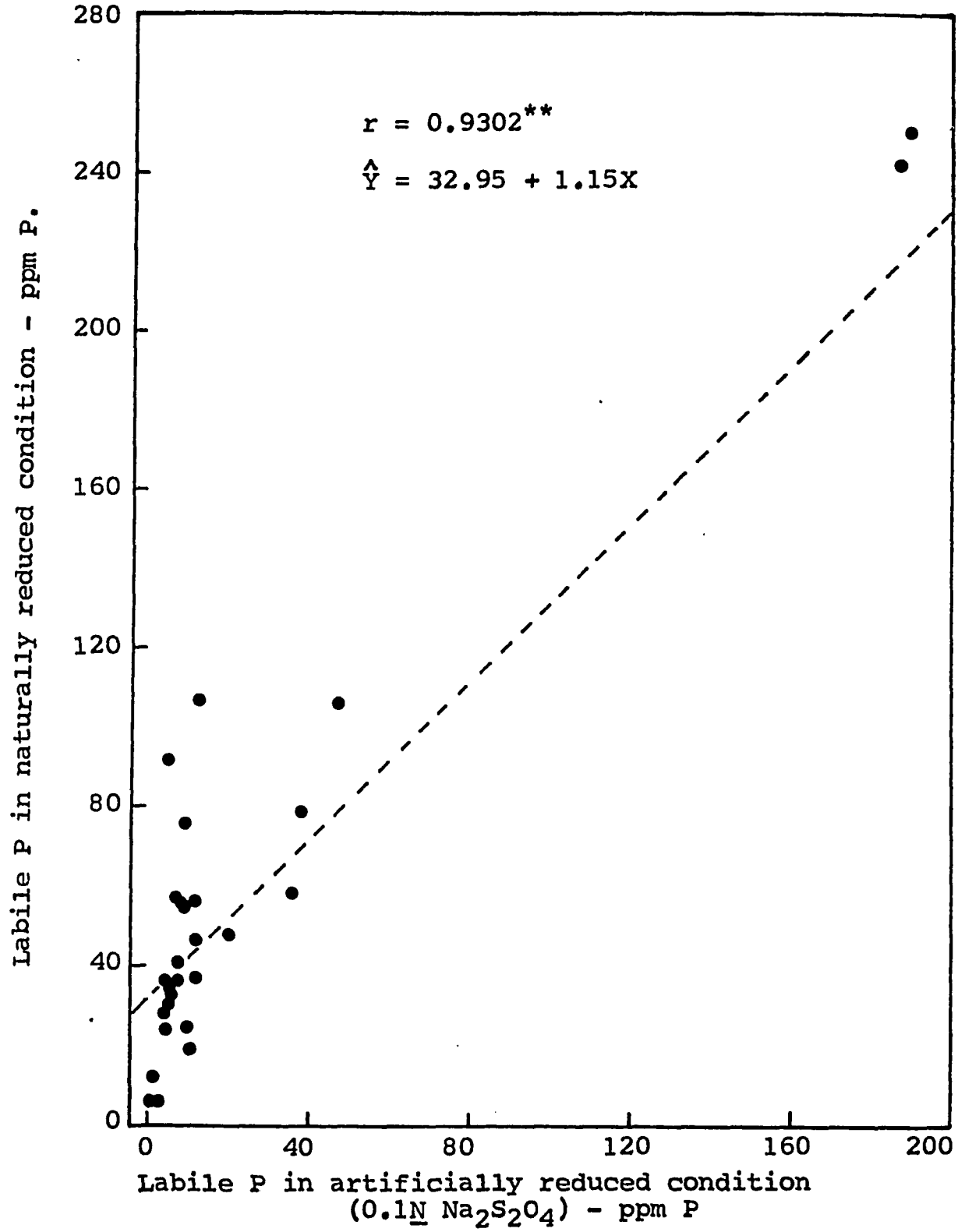

FIGURE 20. Relationship of labile P between naturally reduced and artificially reduced conditions using 0.60 uCi of ^{32}P.

reduced condition against 0.2N $Na_2S_2O_4$, and 0.1N $Na_2S_2O_4$ were 0.9383**, and 0.9302** respectively. Figure 20 showed the relationship of labile P between naturally reduced and artificially reduced conditions using 0.60 uCi of ^{32}P. The naturally oxidized against 0.1N $Na_2S_2O_4$ had an r value of 0.9166** while against naturally reduced the r was 0.8443**. This demonstrated that when a higher concentration of ^{32}P was used, the naturally reduced and artificially reduced had a higher r value compared to the naturally reduced against the naturally oxidized conditions. This gave a good indication that further work on labile phosphorus under these conditions might be beneficial.

Inorganic Phosphorus Fractions in Air-Dried Soils by Chang and Jackson's Procedure.

Table 36 shows the values of inorganic phosphorus fractions in the air-dried soils following the procedure of Chang and Jackson.

The only significant R^2 value was observed with the Al-P fraction using the quadratic equation (R^2 = 0.4201**) and the cubic equation (R^2 = 0.4676**) as shown in Table 37. The regression equation for the quadratic equation was:

$$\hat{Y} = 68.41 + 1.84X - 0.024X^2,$$

and the regression equation in the cubic equation was:

$$\hat{Y} = 62.95 + 3.16X - 0.085X^2 + 0.0007X^3$$

Table 36

Inorganic Phosphate Fractions on Aerated Soils by Chang and Jackson's Procedure - ppm

Soil Series	Year	WS & LB-P	Al-P	Fe-P	Ca-P	RS Fe-P	O. Al & Fe-P	Fe-P + RS Fe-P + O. Al & Fe-P
Midland sil	1963	0.2	6.6	22.8	10.0	32.9	3.4	59.1
Iberia c	1964	0.3	16.6	51.9	51.8	20.2	11.4	83.5
Crowley sil	1964	0.6	6.9	22.8	5.2	21.0	3.4	47.2
Bernard vfsl	1964	0.2	15.2	8.3	2.2	52.0	2.6	62.9
Harris sil	1964	0.2	19.8	30.1	5.4	45.5	5.1	80.7
Crowley sil	1964	0.4	2.9	17.6	5.4	34.8	5.3	57.7
Midland sil	1964	0.7	15.1	35.3	18.2	28.7	4.0	68.0
Sharkey c	1964	0.6	67.4	226.2	88.4	56.5	11.6	294.3
Alligator sicl	1965	0.4	29.1	103.8	33.8	5.0	6.2	115.0
Midland fsl	1965	1.0	6.9	8.3	3.8	5.7	2.8	16.8
Harris sil	1965	0.6	24.4	22.8	5.6	2.3	3.4	28.5
Crowley sil	1965	0.4	4.3	37.4	6.2	3.1	6.0	46.5
Midland sil	1965	0.4	10.5	21.8	4.7	5.0	4.0	30.8
Sharkey c	1965	0.5	64.6	214.8	27.7	3.1	16.2	234.1
Midland fsl	1966	1.3	15.0	8.3	1.9	16.4	2.6	27.3
Crowley sil	1966	0.7	7.5	18.7	2.6	8.4	3.8	30.9
Patoutville sil	1966	0.6	13.0	72.6	23.0	9.9	10.3	92.8
Crowley sil	1966	0.4	3.2	24.9	6.6	13.8	4.0	42.7

Table 36 (Continued)

Soil Series	Year	WS & LB-P	Al-P	Fe-P	Ca-P	RS Fe-P	O. Al & Fe-P	Fe-P + RS Fe-P + O. Al & Fe-P
Midland sil	1966	0.7	5.8	22.8	10.2	11.8	3.0	37.6
Midland fsl	1967	1.9	11.6	8.3	5.4	17.2	2.8	28.3
Patoutville sil	1967	0.1	10.0	72.6	15.6	13.0	14.4	100.0
Crowley sil	1971	0.4	2.6	27.0	4.2	9.9	5.8	42.7
Crowley sil	1971	0.4	3.2	27.0	5.2	11.8	5.2	44.0
Crowley sil	1972	0.4	4.6	35.3	12.4	15.7	4.0	55.0
Crowley sil	1972	0.5	5.1	30.1	10.0	27.9	4.2	62.2
Crowley sil	1973	0.4	3.4	27.0	7.1	24.8	4.4	56.2
Crowley sil	1973	0.3	2.2	20.8	4.2	32.9	3.8	57.5
Jeanerette sil	1974	3.4	51.8	44.6	32.0	53.1	3.2	100.9
Mean =		0.6	15.3	45.1	14.6	20.8	5.6	71.5

WS & LB-P = Water soluble and loosely-bound phosphate; Al-P = Aluminium phosphate; Fe-P = Iron phosphate; Ca-P = Calcium phosphate; RS Fe-P = Reductant soluble iron phosphate; O. Al & Fe-P = Occluded Aluminium and iron phosphate; Fe-P + RS Fe-P + O. Al & Fe-P = Total of iron phosphate, reductant soluble iron phosphate, and occluded aluminium and iron phosphate.

Table 37

The R^2 values of the various phosphorus fractions using Chang and Jackson's procedure with percent yield of rice using Linear equation, Quadratic equation and Cubic equation

Extraction Procedure	Linear Equation	Quadratic Equation	Cubic Equation
24			
I. WS & LB - P (Water soluble and loosely bound phosphate	0.0638	0.0648	0.0648
II. Al - P (Aluminum phosphate)	0.1520	0.4201**	0.4676**
III. Fe - P (Iron phosphate)	0.0456	0.1014	0.1025
IV. Ca - P (Calcium phosphate)	0.0964	0.1800	0.1802
V. RS Fe - P (Reductant soluble iron phosphate)	0.0059	0.0668	0.0669
VI. O. Al & Fe - P (Occluded aluminum and iron phosphate)	0.0249	0.0556	0.1858
VII. Fe-P+RS Fe-P+ O.Al & Fe-P (Summation of iron phosphate reduction soluble iron phosphate and occluded aluminum and iron phosphate)	0.0358	0.0689	0.0746

Relationship of Eh and pH Against the Percent Yield of Rice

The Eh and pH values obtained were shown in Tables 38 to 41. There were no significant simple coefficients of determination in either the Eh or pH of the naturally oxidized and the naturally reduced conditions with percent yield of rice. On the contrary, there was significant coefficient of determination (at 5% level) between the percent yield of rice and the Eh values determined by artificial reduction at both concentrations of $Na_2S_2O_4$ used.

For the pH, there was significant coefficient of determination in both the artificially reduced conditions.

The Eh determined by 0.1N $Na_2S_2O_4$ was significant using the linear and quadratic equations with values of 0.2133* and 0.2413* respectively. The regression equation was:

$$\hat{Y} = 32.98 - 0.54X - 0.001X^2$$

On the contrary, the pH value in the 0.1N $Na_2S_2O_4$ system was not significant using the quadratic equation, but the linear and cubic equations showed significant R^2 with values of 0.2055* and 0.2990* respectively.

The Eh values determined by 0.2N $Na_2S_2O_4$ gave significant R^2 values in the linear and quadratic equations of 0.1899* and 0.2384* in the order mentioned. The pH had significant coefficient of determination values using both the linear and quadratic equations with values of 0.2070* and 0.2282* respectively.

Table 38

Eh and pH Measurements in Oxidized Condition of Soils

Soil Series	Year	Eh (mV)	pH
Midland sil	1963	364	6.4
Iberia c	1964	350	6.6
Crowley sil	1964	353	6.3
Bernard vfsl	1964	396	5.3
Harris sil	1964	376	5.5
Crowley sil	1964	359	7.0
Midland sil	1964	380	6.6
Sharkey c	1964	276	7.0
Alligator sicl	1965	380	6.0
Midland fsl	1965	380	6.4
Harris sil	1965	403	6.0
Crowley sil	1965	394	6.9
Midland sil	1965	412	6.6
Sharkey c	1965	216	7.0
Midland fsl	1966	353	5.8
Crowley sil	1966	426	5.2
Patoutville sil	1966	374	7.1
Crowley sil	1966	395	6.8
Midland sil	1966	408	6.5
Midland fsl	1967	442	5.9
Patoutville sil	1967	422	6.8
Crowley sil	1971	428	6.8
Crowley sil	1971	436	6.9
Crowley sil	1972	428	6.8
Crowley sil	1972	449	6.4
Crowley sil	1973	460	6.4
Crowley sil	1973	458	6.7
Jeanerette sil	1974	418	7.0

Table 39

Eh and pH Measurements in Natural Reduction Condition of Soils

Soil Series	Year	Eh (mV)	pH
Midland sil	1963	117	6.9
Iberia c	1964	84	7.1
Crowley sil	1964	99	6.9
Bernard vfsl	1964	303	5.6
Harris sil	1964	186	6.5
Crowley sil	1964	74	7.0
Midland sil	1964	101	6.9
Sharkey c	1964	-15	7.2
Alligator sicl	1965	35	7.0
Midland fsl	1965	202	6.6
Harris sil	1965	170	6.7
Crowley sil	1965	74	7.0
Midland sil	1965	123	6.8
Sharkey c	1965	-8	7.2
Midland fsl	1966	188	6.4
Crowley sil	1966	120	6.8
Patoutville sil	1966	71	7.0
Crowley sil	1966	64	6.9
Midland sil	1966	97	6.9
Midland fsl	1967	229	6.2
Patoutville sil	1967	80	6.9
Crowley sil	1971	63	7.0
Crowley sil	1971	57	7.0
Crowley sil	1972	60	7.0
Crowley sil	1972	66	7.0
Crowley sil	1973	72	6.9
Crowley sil	1973	64	7.0
Jeanerette sil	1974	61	7.2

Table 40

Eh and pH Measurements in Artificial Reduction Condition (0.1N $Na_2S_2O_4$) of Soils

Soil Series	Year	Eh (mV)	pH
Midland sil	1963	-215	3.8
Iberia c	1964	-321	5.4
Crowley sil	1964	-268	4.2
Bernard vfsl	1964	-174	3.6
Harris sil	1964	-219	3.9
Crowley sil	1964	-322	5.4
Midland sil	1964	-186	3.6
Sharkey c	1964	-330	5.6
Alligator sicl	1965	-298	5.0
Midland fsl	1965	-153	3.4
Harris sil	1965	-194	3.7
Crowley sil	1965	-336	5.7
Midland sil	1965	-180	3.6
Sharkey c	1965	-324	5.6
Midland sil	1966	-132	3.3
Crowley sil	1966	-230	4.1
Patoutville sil	1966	-344	5.8
Crowley sil	1966	-338	5.6
Midland sil	1966	-217	3.9
Midland fsl	1967	-158	3.4
Patoutville sil	1967	-332	5.6
Crowley sil	1971	-324	5.4
Crowley sil	1971	-336	5.6
Crowley sil	1972	-326	5.4
Crowley sil	1972	-322	5.4
Crowley sil	1973	-334	5.6
Crowley sil	1973	-322	5.4
Jeanerette sil	1974	-204	3.9

Table 41

Eh and pH Measurements in Artificial Reduction Condition (0.2N $Na_2S_2O_4$) of Soils

Soil Series	Year	Eh (mV)	pH
Midland sil	1963	-279	4.4
Iberia c	1964	-329	5.5
Crowley sil	1964	-312	5.1
Bernard vfsl	1964	-250	4.2
Harris sil	1964	-261	4.3
Crowley sil	1964	-328	5.5
Midland sil	1964	-240	4.0
Sharkey c	1964	-326	5.5
Alligator sicl	1965	-322	5.4
Midland fsl	1965	-259	4.2
Harris sil	1965	-274	4.4
Crowley sil	1965	-345	5.8
Midland sil	1965	-254	4.2
Sharkey c	1965	-332	5.6
Midland fsl	1966	-213	3.8
Crowley sil	1966	-293	4.8
Patoutville sil	1966	-339	5.5
Crowley sil	1966	-342	5.6
Midland sil	1966	-271	4.4
Midland fsl	1967	-222	3.8
Patoutville sil	1967	-338	5.6
Crowley sil	1971	-334	5.5
Crowley sil	1971	-343	5.6
Crowley sil	1972	-339	5.6
Crowley sil	1972	-336	5.5
Crowley sil	1973	-343	5.6
Crowley sil	1973	-335	5.5
Jeanerette sil	1974	-283	4.3

Table 42

Coefficients of Determination of Eh and pH under Naturally Oxidized, Naturally Reduced, and Artificially Reduced Conditions with Percent Yield of Rice Using Linear, Quadratic, and Cubic Equations

No.	Extraction Procedure	r^2 Linear Equation	R^2 Quadratic Equation	R^2 Cubic Equation
25(i)	Eh by Natural Oxidation	0.0409	0.0449	0.0473
(ii)	pH by Natural Oxidation	0.0623	0.1110	0.1464
26(i)	Eh by Natural Reduction	0.0155	0.0827	0.1230
(ii)	pH by Natural Reduction	0.0005	0.0044	0.0634
27(i)	Eh by Artificial Reduction (0.1N $Na_2S_2O_4$)	0.2133*	0.2413*	0.2489
(ii)	pH by Artificial Reduction (0.1N $Na_2S_2O_4$)	0.2055*	0.2062	0.2990*
28(i)	Eh by Artificial Reduction (0.2N $Na_2S_2O_4$)	0.1899*	0.2384*	0.2417
(ii)	pH by Artificial Reduction (0.2N $Na_2S_2O_4$)	0.2070*	0.2282*	0.2283

Partitioning Single Response Data

Cate and Nelson (1965) developed a graphical method for partitioning the two-dimensional percentage yield versus soil test level scatter into two groups. In addition, Cate and Nelson (1971) and Nelson and Anderson (1971) developed the Analysis of Variance Methods for separating the two groups of soils. The soil test value separating the two groups described above was termed the "critical level".

In this investigation, combinations of the above methods were used to determine the critical levels of P released in the naturally oxidized, naturally and artificially reduced conditions and P extracted by chemical extractant in the air-dried naturally reduced and artificially reduced conditions. First of all the graphical method was used to separate the two groups just by looking at the data points. These critical levels were confirmed by calculating the analysis of variance where the percentage yield data was separated into two classes based upon maximization of the class sum of squares in a one-way analysis of variance following the method of Cate and Nelson (1971). The procedure is outlined as follows:

1. Percentage yield (Y) is calculated for each location using the equation described earlier.
2. Soil test values, X, are obtained for each location.
3. The data are ordered in an array based upon

rankings of the X values, i.e., soil test values. The (X,Y) pairs are maintained in this order throughout the analyses.

4. Starting with the partition that will place two points to the left and ending with that which will place two to the right of the partition, the class sum of squares is calculated according to techniques used in an analysis of variance for a one way classification, i.e.,

$$\text{Class Sum of Squares} = \frac{\left[\text{Total of percentage yields for Class 1}\right]^2}{n_1} + \frac{\left[\text{Total of percentage yields for Class 2}\right]^2}{n_2} - \frac{\left[\text{Total of percentage yields for both classes}\right]^2}{n}$$

where

n_1 = number of observations in Class 1 (to the left of the partition);

n_2 = number of observations in Class 2 (to the right of the partition); and

n = total number of observations ($n_1 + n_2$).

In successive steps the partition is moved one point to the right and a new Class Sum of Squares is calculated until the partition is two points from the right.

5. The Class Sum of Squares is then divided by the Total Corrected Sum of Squares for percentage yields to obtain R^2. Total Corrected Sum of

Squares = $\Sigma y^2 = \Sigma Y^2 - (\Sigma Y)^2/n$.

6. By this simple interative process, a series of R^2 values is obtained for divisions made at various levels of X. The critical level of X is taken as that level of X-division for which R^2 is maximum.

A constant divisor (Σy^2) is used in calculating all R^2 values. Hence, one could achieve the same results maximizing the Class Sum of Squares.

The range of values, the means, the R^2s and critical levels were given in Table 43, and Figures 21 to 24.

It could be seen that all the critical levels determined, were below the respective means of the soil test P determination. As shown earlier, P response in rice rose up sharply at low levels of P and then began to level off at higher levels of P. So, it would not be a surprise to see that the critical levels were found mostly at the lower range.

Looking at the naturally oxidized, naturally reduced, and artificially reduced conditions, it was obvious that the artificially reduced condition had the highest critical level because much more P was being released to the solution in this condition, 16.8 ppm P in 0.1N $Na_2S_2O_4$ and 15.4 ppm P in 0.2N $Na_2S_2O_4$. The naturally reduced condition had a critical level value of 3.8 ppm P while the naturally oxidized condition had 1.8 ppm P.

When air-dried soils were extracted, it was found that Bray No. 2 had a mean of 37.5 ppm P and a critical value of 12.6 ppm P. The Bray No. 1 had a mean of 18.2 ppm P and critical value of 8.6 ppm P. On the other hand 0.2N HCl had a higher mean value of 30.7 ppm P but the critical level was 5.8 ppm P, lower than the critical level of Bray No. 1.

Reducing the soils naturally before extracting the P, increased the mean values as well as the critical levels consistently. The same observation mentioned earlier existed here with the naturally reduced + Bray No. 2 had a mean of 85.1 ppm P and a critical level of 53.0 ppm P while the Bray No. 1 had a mean of 67.7 ppm P and a critical level of 32.4 ppm P. Again, 0.2N HCl had a higher mean than Bray No. 1 but the critical level was smaller (27.1 ppm P).

The means and critical levels of all the five chemical extractants in artificially reduced was lower than those naturally reduced and chemically extracted. The Bray No. 2 had a mean of 74.7 ppm P and critical level of 37.4 ppm P. Here, the 0.2N HCl had a higher critical level of 32.2 ppm P while the Bray No. 1 had 24.1 ppm P, followed by Kapp's Texas Buffer and 0.5M $NaHCO_3$.

The advantage of determining the critical level is that the soils could be separated into two definitive groups:- (i) those on the left of the critical level having a probability of response to fertilizer that is large and (ii) those to the right of the critical level having a probability of

Table 43

The Range, Mean, R^2, and Critical Level of Soil Test Phosphorus for Soil Sites Grown with Rice

No.	Extraction Procedure	Range of P extracted (ppm)	Mean Value of P (ppm)	R^2	Critical Level of P (ppm)
1.	Naturally Oxidized	0.6-10.4	3.8	0.4357	1.8
2.	Naturally Reduced	0.8-44.8	10.8	0.4773	3.8
3.	Artificially Reduced (0.1N $Na_2S_2O_4$)	2.4-308.2	40.8	0.4377	16.8
4.	Artificially Reduced (0.2N $Na_2S_2O_4$)	2.8-321.8	45.3	0.3802	15.4
5.	0.5M $NaHCO_3$	2.0-32.9	8.2	0.5503	4.1
6.	Kapp's Texas Buffer	1.1-33.2	7.2	0.5314	2.8
7.	Bray No.1	2.5-70.1	18.2	0.6063	8.6
8.	Bray No.2	4.5-235.6	37.5	0.5578	12.6
9.	0.2N HCl	1.3-240.8	30.7	0.6063	5.8
10.	Naturally Reduced + 0.5M $NaHCO_3$	2.1-76.5	21.9	0.4736	15.3
11.	Naturally Reduced + Kapp's Texas Buffer	5.4-283.7	46.9	0.4329	20.3

Table 43 (continued)

No.	Extraction Procedure	Range of P extracted (ppm)	Mean Value of P (ppm)	R^2	Critical Level of P (ppm)
12.	Naturally Reduced + Bray No.1	16.6-315.9	67.7	0.5503	32.4
13.	Naturally Reduced + Bray No.2	12.4-544.5	85.1	0.3705	53.0
14.	Naturally Reduced + 0.2N HCl	8.9-525.2	78.3	0.5029	27.1
15.	Artificially Reduced + 0.5M $NaHCO_3$	6.3- 56.7	14.4	0.1912	13.4
16.	Artificially Reduced + Kapp's Texas Buffer	3.7-184.3	30.8	0.1209	15.3
17.	Artificially Reduced + Bray No.1	8.2-284.8	46.6	0.4694	24.1
18.	Artificially Reduced + Bray No.2	16.5-464.6	74.7	0.2043	37.4
19.	Artificially Reduced + 0.2N HCl	13.4-519.5	74.5	0.2030	32.2

response to fertilizer that is small.

The critical level could provide a definite decision point, which could be the basis for a simple classification of soils on the basis of soil test results. By knowing the critical level of the soil, efficiency of fertilizer application could be improved. This is especially important when the price of fertilizer is high. Figures 21 and 22 demonstrated how the critical level changed from a lower concentration of extractant to a higher ones. Figure 21 showed Bray No.1 extractant had a critical level of 8.6 ppm P. But when stronger chemical was used the slope of the graph shifted as shown in Bray No.2 having a critical level of 12.6 ppm P. Artificially reducing the soils and then extracting it with Bray No.1 further shifted the curve and the critical level to the right (Figure 23).

The same observation was observed in Figure 24, when Bray No.1 was used to extract a naturally reduced soil.

Effect of Reduction on Phosphorus Extraction

The naturally reduced and the artificially reduced conditions increased the amount of phosphorus extracted. As a result of that the mean, range, and critical level increased (Table 43, and Figures 21 to 24).

What could have happened was that the ferric phosphate is converted to the ferrous form. This does not necessarily mean that ferrous phosphate is more water-soluble

than ferric phosphate, but the reduction conditions cause the ferrous form to be more succeptible to extraction. The same effect was shown in the other extractants.

To Find the Validity of Bray-Mitscherlich and Langmuir Equations of Phosphorus Extraction in Oxidized (Air-Dried), Naturally Reduced, and Artificially Reduced Conditions

It has been shown that Bray (1948) used the Bray-Mitscherlich equation to fit crop response to phosphorus fertilization with a lot of success. In this section the validity of two equations were evaluated in predicting percent yield, namely: (1) Bray-Mitscherlich equation, and (2) Langmuir equation. According to Nelson and Anderson (1977) Bray-Mitscherlich was a good equation to use where a wide variety of soil conditions and other variability existed. The line for the equation passes through the origin and reaches a maximum.

(1) Bray-Mitscherlich Equation

$$\log_{10} (A - Y) = \log_{10} A - CP \quad \ldots\ldots\ldots\ldots\ldots (2)$$

$$C = \frac{2 - \left[\log_{10} (A - Y)\right]}{P} \quad \ldots\ldots\ldots\ldots\ldots (3)$$

$$\hat{Y}_B = A - \text{antilog } (2 - \bar{C}P) \quad \ldots\ldots\ldots\ldots\ldots (4)$$

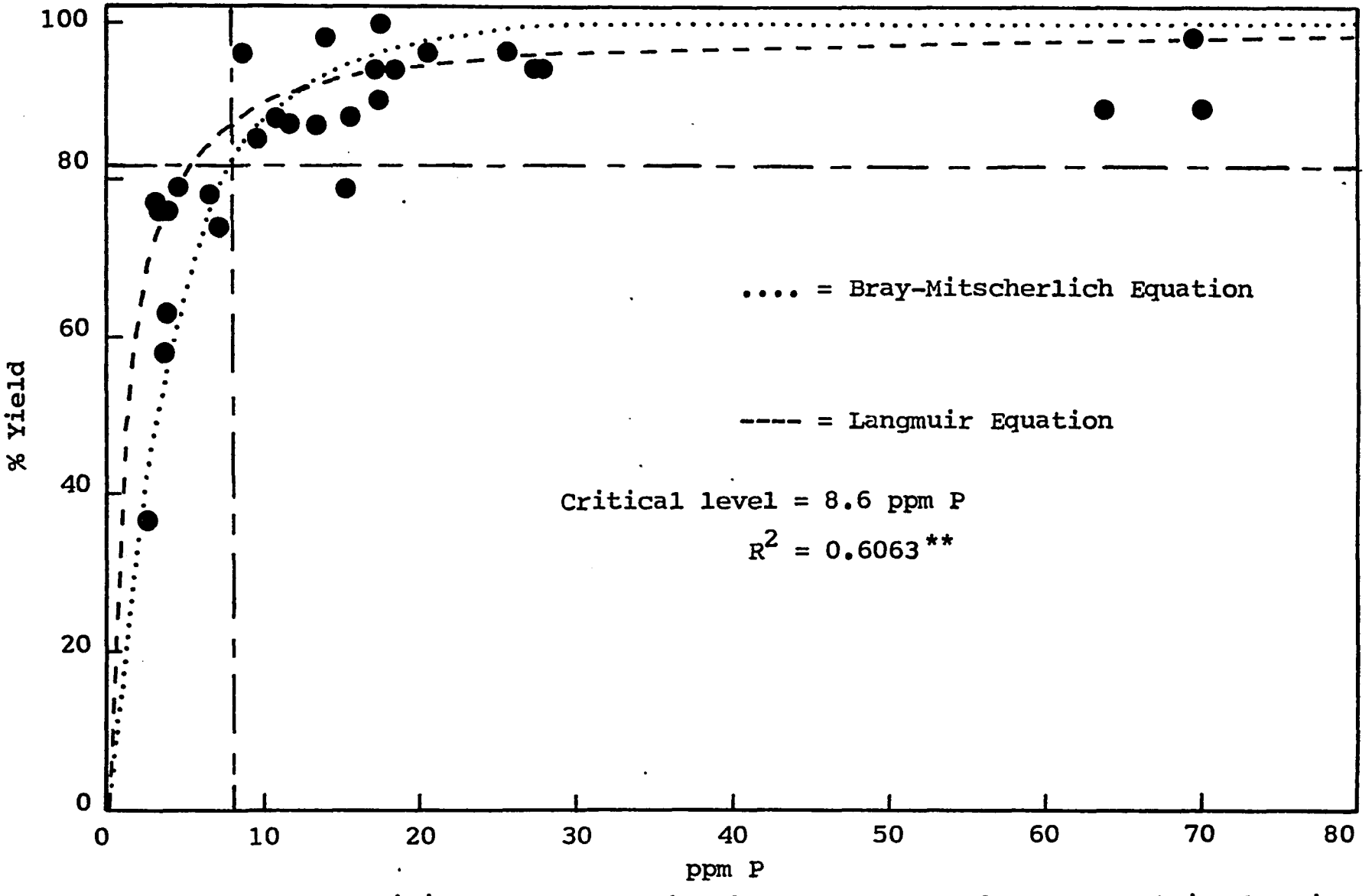

FIGURE 21. The "critical level" of phosphorus extracted by Bray No.1 in the air-dried soil - ppm P.

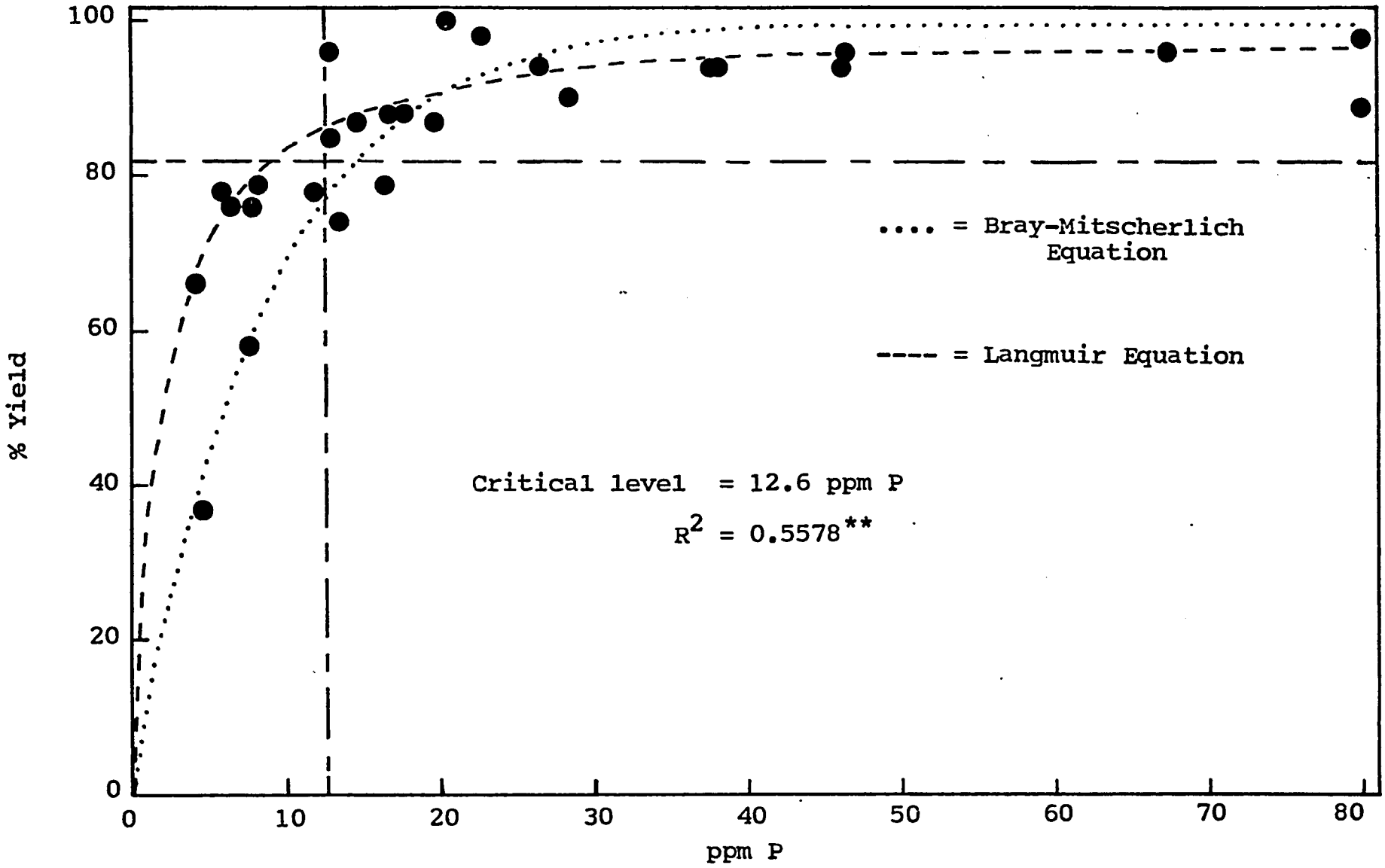

FIGURE 22. The "critical level" of phosphorus extracted by Bray No.2 in the air-dried soil - ppm P.

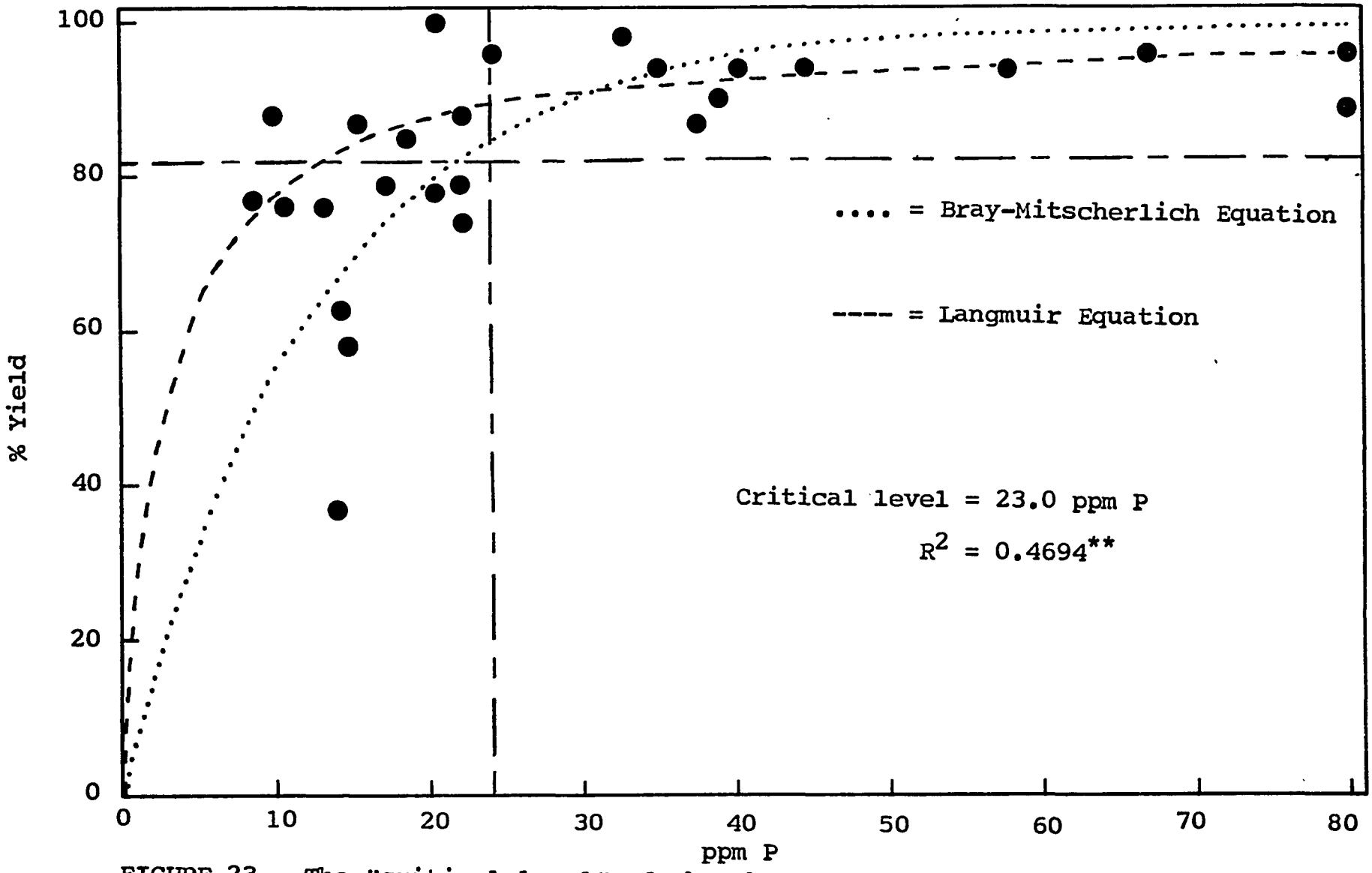

FIGURE 23. The "critical level" of phosphorus extracted by Bray No.1 in the artificially reduced soil - ppm P.

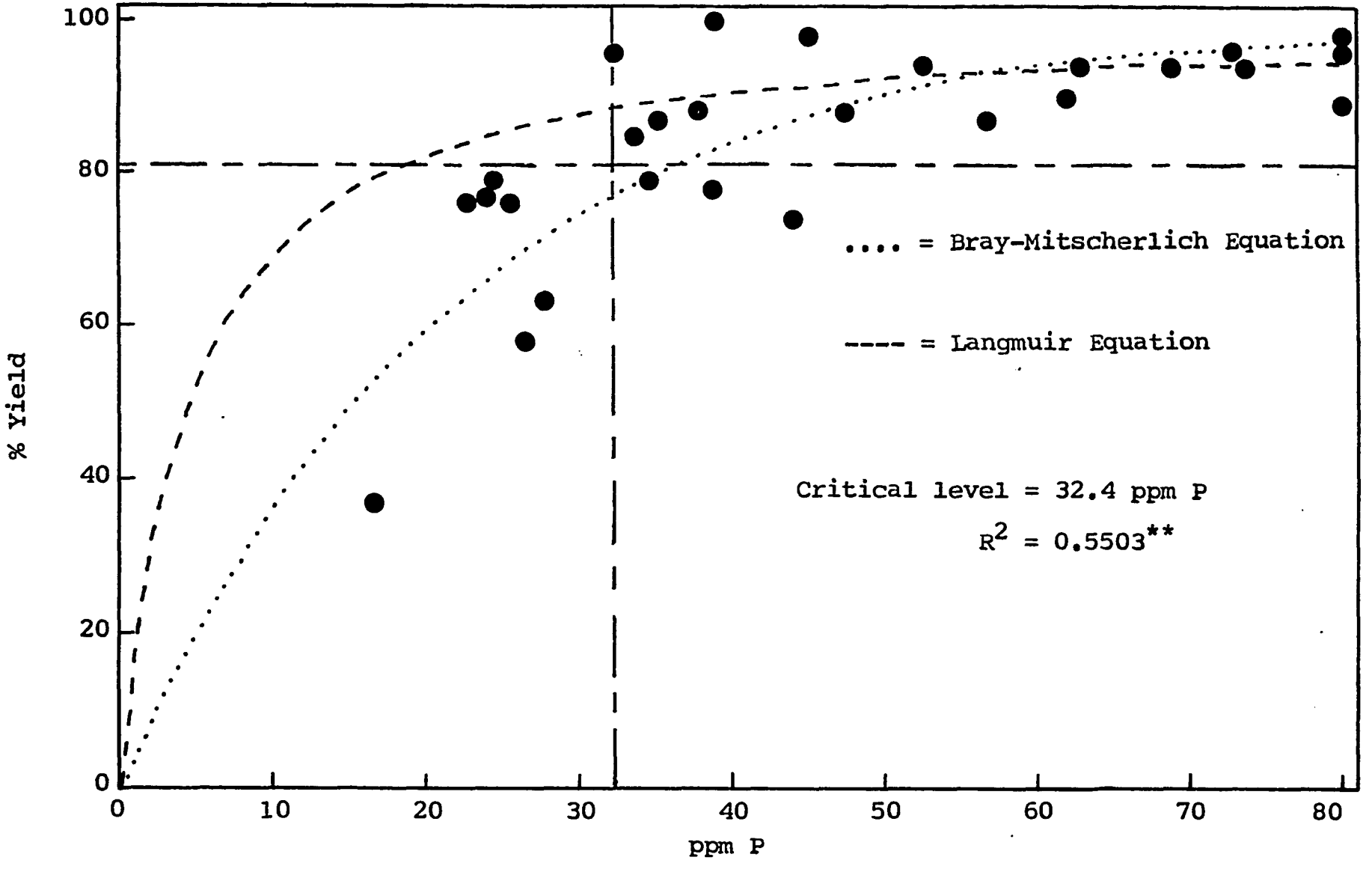

FIGURE 24. The "critical level" of phosphorus extracted by Bray No.1 in the naturally reduced soil - ppm P.

where,

A = 100, i.e. maximum percent yield,

Y = percent yield,

P = soil test value of phosphorus concentration, ppm,

C = constant,

$\hat{Y}_B$ = Bray-Mitscherlich percent yield predictions,

$\bar{C}$ = Mean for a particular soil test for 27 samples.

In each soil test, C was calculated for every soil site using equation number 3. Since methods of calculating an individual C when $Y \geq 100$, and $\log_{10}(100 - Y)$ is indeterminate were not given, therefore soil number 215 was excluded in the data transformation. The 27 C's were averaged and resulting mean ($\bar{C}$) was calculated (Table 44). Equation number 4 was used to transform the Bray-Mitscherlich percent yield corresponding to soil test phosphorus in each chemical extractant and a continuous best fitting curve was constructed. Equation number 4 could also be used to give a prediction of percent yield.

(2) Langmuir Equation

The Langmuir adsorption isotherm (Langmuir 1918) was developed through the kinetic theory of gases to describe adsorption of gases on solids. The line passes through the origin and approaches a maximum asymptotically.

$$Y = \frac{AKP}{1+KP} \quad \text{.....(5)}$$

$$K = \frac{Y}{P(A - Y)} \quad \text{.....(6)}$$

$$\hat{Y}_L = \frac{AKP}{1 + \bar{K}P} \quad \text{.....(7)}$$

where, A = 100, i.e. maximum percent yield,

Y = percent yield,

P = soil test value of phosphorus concentration, ppm,

K = constant for a particular soil,

$\hat{Y}_L$ = Langmuir prediction of percent yield,

$\bar{K}$ = Mean for a particular soil test for 27 samples.

For the Langmuir equation, a constant K was calculated for each observation using equation number 6 by inserting the percent yield data and the soil test phosphorus into the equation. Since Y/zero is indeterminate, K was not calculated when $Y \geqslant 100$, therefore soil number 215 was excluded in this equation for the data transformation.

A mean constant ($\bar{K}$) was computed for each soil extractant and this value served as a constant for that particular extractant (Table 44). Using equation number 7, a continuous curve was constructed following the same procedure done in the Bray-Mitscherlich equation.

In the Bray-Mitscherlich and Langmuir equations,

Table 44

The Equation Coefficients, Sum of Squares of Deviations, and Percent Deviations, Using Bray-Mitscherlich and Langmuir Equations

Extraction Procedure	Equation Coefficients		Sum of Squares of Deviations		Percent Sum of Squares of Deviations	
	$\bar{C}$	$\bar{K}$	Bray-Mitscherlich Equation	Langmuir Equation	Bray-Mitscherlich Equation	Langmuir Equation
1. Naturally Oxidized	0.38310	3.52139	4564.63	3910.64	90.95	77.92
2. Naturally Reduced	0.26575	2.30935	4847.97	2214.28	96.59	44.12
3. Artificially Reduced (0.1N $Na_2S_2O_4$	0.05635	0.52205	4525.97	3192.83	90.18	63.62
4. Artificially Reduced (0.2N $Na_2S_2O_4$	0.05242	0.49989	5915.34	3598.36	117.86	71.70
5. 0.5M $NaHCO_3$	0.16466	1.89836	4106.24	4742.65	81.82	94.50
6. Kapp's Texas Buffer	0.23578	2.40572	2550.96	2760.07	50.83	54.99
7. Bray No.1	0.08822	0.84569	3816.07	2233.62	76.03	44.50

Table 44 (continued)

Extraction Procedure	Equation Coefficients		Sum of Squares of Deviations		Percent Sum of Squares of Deviations	
	$\bar{C}$	$\bar{K}$	Bray-Mitscherlich Equation	Langmuir Equation	Bray-Mitscherlich Equation	Langmuir Equation
8. Bray No.2	0.05155	0.50989	2877.76	2547.82	57.34	50.76
9. 0.2N HCl	0.11176	0.99924	4794.94	1530.67	95.54	31.09
10. Naturally Reduced + 0.5M $NaHCO_3$	0.06590	0.68301	3155.51	2606.86	62.87	51.94
11. Naturally Reduced + Kapp's Texas Buffer	0.03786	0.38179	3482.92	3182.47	69.40	63.41
12. Naturally Reduced + Bray No.1	0.01972	0.22333	1950.36	4130.58	38.86	82.30
13. Naturally Reduced + Bray No.2	0.01933	0.20939	2146.75	3396.79	42.77	67.68
14. Naturally Reduced + 0.2N HCl	0.02469	0.25461	2684.54	2879.90	53.49	57.38

Table 44 (continued)

Extraction Procedure	Equation Coefficients		Sum of Squares of Deviations		Percent Sum of Squares of Deviations	
	$\bar{C}$	$\bar{K}$	Bray-Mitscherlich Equation	Langmuir Equation	Bray-Mitscherlich Equation	Langmuir Equation
15. Artificially Reduced + 0.5M $NaHCO_3$	0.08559	1.03034	5134.32	6020.38	102.30	119.95
16. Artificially Reduced + Kapp's Texas Buffer	0.05955	0.58943	9961.77	6004.17	198.48	119.63
17. Artificially Reduced + Bray No.1	0.03582	0.34590	4546.02	4105.68	90.58	81.80
18. Artificially Reduced + Bray No.2	0.02343	0.27286	5169.39	5404.32	103.00	107.68
19. Artificially Reduced + 0.2N HCl	0.02723	0.30624	5822.74	5350.55	116.02	106.61

instead of using the R^2, Sum of Squares of Deviations from the Bray-Mitscherlich and Langmuir equations were used in order to find out how well the two equations fit the data. Then the percent of deviations was calculated (Table 44). The lower the Sum of Squares of Deviations the better is the extractant. Figures 1 to 19, and 21 to 24 show the best fitting curves of the Bray-Mitscherlich equation (dotted lines) and the Langmuir equation (dashed lines) originating from zero and ending to a maximum of 100%.

Comparing the naturally oxidized, naturally reduced and artificially reduced (0.1N and 0.2N $Na_2S_2O_4$) conditions, it can be seen that the Langmuir equation showed a consistently lower Sum of Squares of Deviations than the Bray-Mitscherlich equation. In the naturally reduced, only 44.12% deviation from the total was recorded while in the naturally oxidized there was 77.92% deviation.

When the air-dried soils were extracted chemically, 0.2N HCl, Bray No.1, and Bray No.2 had a lower percent deviation with values of 31.09%, 44.50%, and 50.76% respectively in the Langmuir equation. On the contrary, Kapp's Texas Buffer and 0.5M $NaHCO_3$ had a lower percent deviation of 50.83% and 81.82% respectively, using the Bray-Mitscherlich equation.

In the chemical extraction of naturally reduced soils, Bray No.1, Bray No.2, and 0.2N HCl had a lower percent deviations of 38.86%, 42.77%, and 53.49% respectively,

using the Bray-Mitscherlich equation. In 0.5M $NaHCO_3$ and Kapp's Texas Buffer, the percent deviation was lower in the Langmuir equation with values of 51.94% and 63.41% respectively.

When the soils were artificially reduced and then chemically extracted, only the Bray No.1 showed percent deviation lower than 100%, with values of 81.80% and 90.58% in the Langmuir and Bray-Mitscherlich equations respectively.

Unfortunately not all the extraction in both equations gave low Sum of Squares of Deviations. In the artificially reduced (0.2N $Na_2S_2O_4$) using the Bray-Mitscherlich equation, the percent deviation was greater than 100%. Chemical extraction in an artificially reduced soils by 0.5M $NaHCO_3$, Kapp's Texas Buffer, Bray No.2, and 0.2N HCl, the percent deviations were greater than 100% in both the Bray-Mitscherlich and Langmuir equations. In this case, the equations would not give any additional advantage.

It is worthwhile mentioning that R^2 is not the only criteria to evaluate the superiority of an equation. Other factors like the shape of the curve should also be taken into consideration. In addition, Sum of Squares of Deviations is as good. For example, the quadratic and cubic equations would give a high R^2 values but the shape of the curves was not desirable (Figure 1b on page 68, and Figure 7b on page 83). On the contrary, the Bray-Mitscherlich and Langmuir equations produce the most desirable curve as far

as phosphorus is concerned (Figures 1 to 19, and 21 to 24). At higher level of soil phosphorus, the point will still fall within the limit of the percent yield in both the Bray-Mitscherlich and Langmuir equations.

Advantages of Using Bray-Mitscherlich and Langmuir Equations

1. Ease of calculation, since both equations can be rearranged (reduced) into a linear form. Regression equations cannot be used (see Figures 1b and 7b) at any P level, since such prediction can at times deviate drastically (and exceeds 100%) from experimental data.
2. Only one parameter (C) or (K) is needed in order to predict the yield versus P test.
3. Even though the predicted C and K values varied significantly among the soil tests, such variation were much less than those encountered for the linear, quadratic, and cubic equations. For instance, the variation of C and K were from 0.019 to 0.383 and 0.2 to 0.35, respectively, i.e., the variation ranged between 17 to 20 folds. For the regression equations such variation were as much as or exceeded 100 folds.

Based on the above discussion, it is recommended that such simple equations be further investigated in their

capabilities of predicting the yield response to phosphorus and ultimately, phosphorus recommendations as based on individual soil tests.

SUMMARY

Twenty-eight soil samples, each represented by a surface horizon, from the major rice areas of Louisiana were used in this investigation. Each sample represented the original soil condition where a replicated fertilizer response experiment was conducted with rice.

The soils were tested for equilibrium P and extractable P by five methods under air-dried, naturally reduced and artificially reduced conditions. The percent yields were related to the P test values using linear, quadratic, cubic, Bray-Mitscherlich and Langmuir equations.

When the naturally oxidized, naturally reduced, and artificially reduced were compared the highest R^2 value using the cubic equation was observed in the naturally reduced followed by 0.1N $Na_2S_2O_4$ artificially reduced, naturally oxidized, and 0.2N $Na_2S_2O_4$ artificially reduced in the descending order. However, when the quadratic equation was used the ranking of R^2 from highest to lowest was: naturally oxidized > 0.1N $Na_2S_2O_4$ artificially reduced > naturally reduced > 0.2N $Na_2S_2O_4$ artificially reduced.

When the quadratic equation was used, the ranking of R^2 from the highest to the lowest was as follows: Bray No. 1 > Kapp's Texas Buffer > Bray No.2 > 0.5M $NaHCO_3$ > 0.2N HCl. The quadratic equation of the Bray No.1 having an R^2

value of 0.5549** was:

$$\hat{Y} = 63.67 + 1.97X - 0.023X^2.$$

When the cubic equation was used, the ranking by the R^2 value remained the same.

Reducing the soils naturally and then extracting them by the chemical methods changed the rankings a little. The ranking of the R^2 by the quadratic equation in a decending order was: naturally reduced + 0.5M $NaHCO_3$ > naturally reduced + Bray No.1 > naturally reduced + Bray No. 2 > naturally reduced + 0.2N HCl > naturally reduced + Kapp's Texas Buffer. The R^2 value in the 0.5M $NaHCO_3$ was 0.5390** and the regression equation was:

$$\hat{Y} = 60.16 + 1.93X - 0.02X^2$$

When the cubic equation was used, the highest R^2 was still observed in the naturally reduced + 0.5M $NaHCO_3$. The Bray No.1 was third on the list.

In the chemical extraction of the artificially reduced soils, using the quadratic equation, only the artificially reduced + Bray No.1 had a significant R^2 of 0.2955* and a regression equation of:

$$\hat{Y} = 72.39 + 0.40X - 0.001X^2$$

Even when the cubic equation was used, it did not increase the significance of the R^2 values of the other extractants used.

It has been indicated earlier that 0.1N $Na_2S_2O_4$ gave good correlation with percent yield of rice. In addition,

artificially reduced gave an added advantage over the naturally reduced. Instead of waiting from two to four weeks for the soils to be naturally reduced, artificially reduced takes only one hour. Unfortunately, a significant R^2 value was only observed when Bray No.1 was used to extract the P after the soil was artificially reduced.

Among the five chemical extractants used for this study, it appeared that Bray No.1 showed a promising ability to correlate extractable P with rice yield. In both air-dried soil and artificially reduced conditions, Bray No.1 had the highest R^2 value. Using cubic equation, Bray No.1 was third when the soil was naturally reduced and then extracted. As far as naturally reduced soil was concerned, 0.5M $NaHCO_3$ ranked the highest.

The Kapp's Texas Buffer was the weakest extractant for extracting P in an air-dried soil while Bray No.2 was the strongest.

The naturally reduced and the artificially reduced conditions increased the amount of phosphorus extracted. This could be due to the conversion of ferric phosphate to ferrous phosphate. This does not mean that ferrous phosphate is more water-soluble than ferric phosphate, but the reduction conditions cause the ferrous form to be more succeptible to extraction.

In the labile phosphorus experiment there were no significant R^2 values in the naturally oxidized, naturally

and artificially reduced soils irrespective of using linear, quadratic or cubic equations.

On the contrary, there were highly significant linear relationship for the labile P between the naturally oxidized, naturally reduced, and artificially reduced condition. When 0.34 uCi of ^{32}P was used, the highest correlation was observed between artificial reduction (0.1N $Na_2S_2O_4$) and natural oxidation ($r = 0.9643^{**}$). However, when 0.60 uCi of ^{32}P was used the highest r was observed between the two different concentrations of $Na_2S_2O_4$ used. The r values of naturally reduced against 0.2N $Na_2S_2O_4$ and 0.1N $Na_2S_2O_4$ were 0.9383^{**} and 0.9302^{**} respectively. This gave a good indication that future investigation in this line of work would be beneficial.

In the inorganic phosphorus fractionation experiment on aerated soils, the only significant R^2 value was observed with the Al-P fraction using either the quadratic or the cubic equation. The regression equation using the quadratic equation having an R^2 of 0.4201^{**} was:

$$\hat{Y} = 68.41 + 1.84X - 0.024X^2$$

There were no significant R^2 values in either the Eh or pH of the naturally oxidized and the naturally reduced conditions. However, there were significant R^2 values (at 5% level) between the percent yield of rice and the Eh and pH values determined by artificially reduced conditions at both concentrations of $Na_2S_2O_4$ used.

Apart from finding the coefficients of determination, of soil test P against percent yield of rice, the critical level of P for each chemical extractant was also determined. In this investigation, the critical level was calculated for P released in the naturally oxidized, naturally reduced, and artificially reduced and P extracted by five chemical extractants in the air-dried, naturally reduced, and artificially reduced conditions using the combination of graphical method and a one-way analysis of variance (Table 43). The graphical method seperated the soils into two groups by examining the data points on the graph. These critical levels were then confirmed by calculating the analysis of variance where the percent yield data was seperated into two classes based upon maximization of the class sum of squares. The advantage of determining the critical level is that the soil could be seperated into two definitive groups:-
(i) those on the left of the critical level having a high probability of response to fertilizer phosphorus and
(ii) those to the right of the critical level having a low probability of response to fertilizer phosphorus. By knowing the critical level of the soil, efficiency of fertilizer application could be improved.

In addition to the linear, quadratic, and cubic regression equations, the Bray-Mitscherlich equation, and Langmuir equation were tested. Equation number 4 on page 144 was used to transform the Bray-Mitscherlich percent

yield corresponding to soil test P in each chemical extrac- and a continuous best fitting curve was constructed. The same thing was done for the Langmuir equation using equation number 7 on page 150. Instead of using the coefficients of determination, the sum of squares of deviation from the Bray-Mitscherlich and Langmuir equations were used in order to find out how well the two equations fit the data. Then the percent amount of deviations was calculated.

Comparing the naturally oxidized, naturally reduced and artificially reduced (0.1N and 0.2N $Na_2S_2O_4$), the Langmuir equation showed a consistantly lower Sum of Squares Deviation than the Bray-Mitscherlich equation. When the air-dried soils were extracted chemically, 0.2N HCl, Bray No.1, and Bray No.2 had a lower percent deviation from the Langmuir equation. In the naturally reduced soils, Bray No.1, Bray No.2, and 0.2N HCl had a lower percent of deviation using the Bray-Mitscherlich equation. In the artificially reduced condition, only the Bray No.1 showed percent of deviation of lower than 100% in both Bray-Mitscherlich and Langmuir equations.

It could be reported here that R^2 is not the only criteria to evaluate the superiority of an equation. Other factors like the shape of the curve should also be taken into consideration. In this respect the quadratic and cubic equations were not desirable. The Bray-Mitscherlich and Langmuir equations produced more desirable curves with the latter slightly superior.

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In 1967, he entered the College of Agriculture, Serdang, Selangor, Malaysia, under the sponsorship of FELDA (Federal Economic and Land Development Authority). He graduated with a diploma in Agriculture in 1970. He was then employed as an assistant manager in one of the FELDA's schemes.

In September, 1971, he was admitted as an undergraduate in Agronomy Department at Louisiana State University, Baton Rouge, under the sponsorship of PSD (Public Service Department), Malaysia. He received a B.S. degree in Agronomy in August, 1973. He continued his studies in the Department of Agronomy at LSU as a graduate

student, majoring in Soil Science. He received his M.S. degree in Agronomy in December, 1975.

He married Zawiah Bte Hashim on 5th March, 1976 and had a son Erwan on 20th May, 1977.

He began Ph.D. studies at Louisiana State University, Baton Rouge, Louisiana immediately after obtaining his M.S. He is currently a member of the American Society of Agronomy and Soil Science Society of America, Madison, Wisconsin, U.S.A.

He is at present a candidate for the degree of Doctor of Philosophy in the Department of Agronomy at the Louisiana State University, Baton Rouge.

EXAMINATION AND THESIS REPORT

Candidate: Alias Bin Husin

Major Field: Agronomy

Title of Thesis: Evaluation of Chemical Methods for Available Soil Phosphorus in Relation to Yield of Rice

Approved:

A. G. Caldwell
Major Professor and Chairman

James B. Ingraham
Dean of the Graduate School

EXAMINING COMMITTEE:

W. M. Selim

Edward M. Lamberton

David B. Mengel

F. G. Peterson

W. H. Patrick, Jr.

Date of Examination:

February 2, 1979